

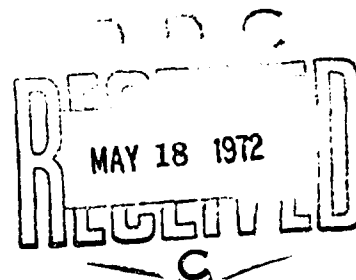
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Technical Memorandum 11-72

ANALYSIS OF PILOT'S EYE MOVEMENTS DURING HELICOPTER FLIGHT

John A. Barnes



April 1972

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HUMAN ENGINEERING LABORATORY



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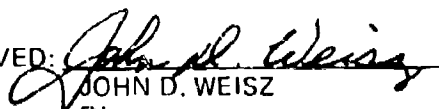
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April 1972

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The aircraft which were flown or simulated in these studies include the U. S. Navy NH-1 (Howard DGA-15), PBX-5-A, and A-4; the U. S. Air Force C-45, T-33, and F-102; the U. S. Army UH-1B; the Boeing 707, the McDonnell-Douglas DC-8, and the Lockheed L-188.

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ANALYSIS OF PILOT'S EYE MOVEMENTS DURING HELICOPTER FLIGHT

INTRODUCTION

The helicopter pilot's eye movements, dwell points and paths of movement, reveal an everchanging pattern which appears to be different, quite different, for each type of maneuver performed. This report will attempt to reveal some of these patterns and point up the differences in patterns occurring between maneuvers and flight conditions. The initial work in this area is given in HEL TM 7-70, Tactical Utility Helicopter Information Transfer Study (1).

The data are presented in a form compatible with that of several current papers on the subject, but differ from the others in that this is real-time actual-flight data taken continuously during 20-minute test missions (Figs. 1 and 2) rather than simulator data or data from one segment of a mission. The major emphasis was placed on instrument flight but information from the terrain following, VFR climb and hover segments of the missions is also included.

METHOD

The report uses the eye movements film secured for the Tactical Utility Helicopter Information Transfer Study (1) as a data base. A condensed version of this study is given in Appendix A.

DATA REDUCTION

One of the more recent reports in the field of eye movement is The Measurement and Analysis of Pilot Scanning and Control Behavior During Simulated Instrument Approaches (16). The authors have taken the earlier work by Fitts, Jones and Milton and converted these results to their data format. In this report the results are also presented in that format so that with continuity across results it may be possible to detect some similarities that would otherwise remain hidden. The following symbology will be used to report the results of this work. For a given flight maneuver or run:

T_R	Duration of run in seconds
T_i	Sum of the time spent fixating on a point/instrument
$\overline{T_d}$	Mean fixation/dwell time on a point/instrument

N_i	Sum of fixations on a point/instrument
N_u	Sum of fixations not identified because of blinks, movement, and movement beyond system limits, etc.
n	Dwell fraction; the portion of run time spent on a point
M	Sum of fixation points
\bar{f}_s	Scan rate; the rate at which points are "looked at"
N_m	Sum of fixations on all fixation points.

The following formulae are used to determine the results reported:

1. $T_R = T_2 - T_1$ where T_2 was the clock time at the end of a run and T_1 was the clock time at the start of a run. In this actual flight work, the times at the start and finish of a maneuver were recorded on the flight log; when the data film was read, the frame number at the start and end of a run were used for T_1 and T_2 and their difference was divided by frame rate to give an accurate value of T_R .
2. $T_i = \sum_{k=1}^{N_i} T_{ik}$ unit is in seconds
3. $\bar{T}_d = 1/N_i \sum_{k=1}^{N_i} T_{dk} = T_i/N_i$ unit is seconds/fixation point
4. $\bar{f}_s = N_i/T_R$ unit is fixation/point/run time
5. $n = T_i/T_R$ unit is sum of fixation time/run time
6. $N = N_u + \sum_{i=1}^M N_i$ unit is fixations

MANEUVER	START	END
Take Off	00:00	
Hover, IGE	00:00	00:02
Vertical Climb	00:02	00:04
Cruise, IFR	00:04	00:07
Standard Rate Turn, IFR	00:07	00:08
Climb, IFR	00:08	00:09
Cruise, IFR	00:09	00:12
180° Turn, IFR	00:12	00:13
Steep Approach IFR	00:13	00:15
Hover, OGE, VFR	00:15	00:16
Vertical Descent	00:16	00:18
Land		00:19

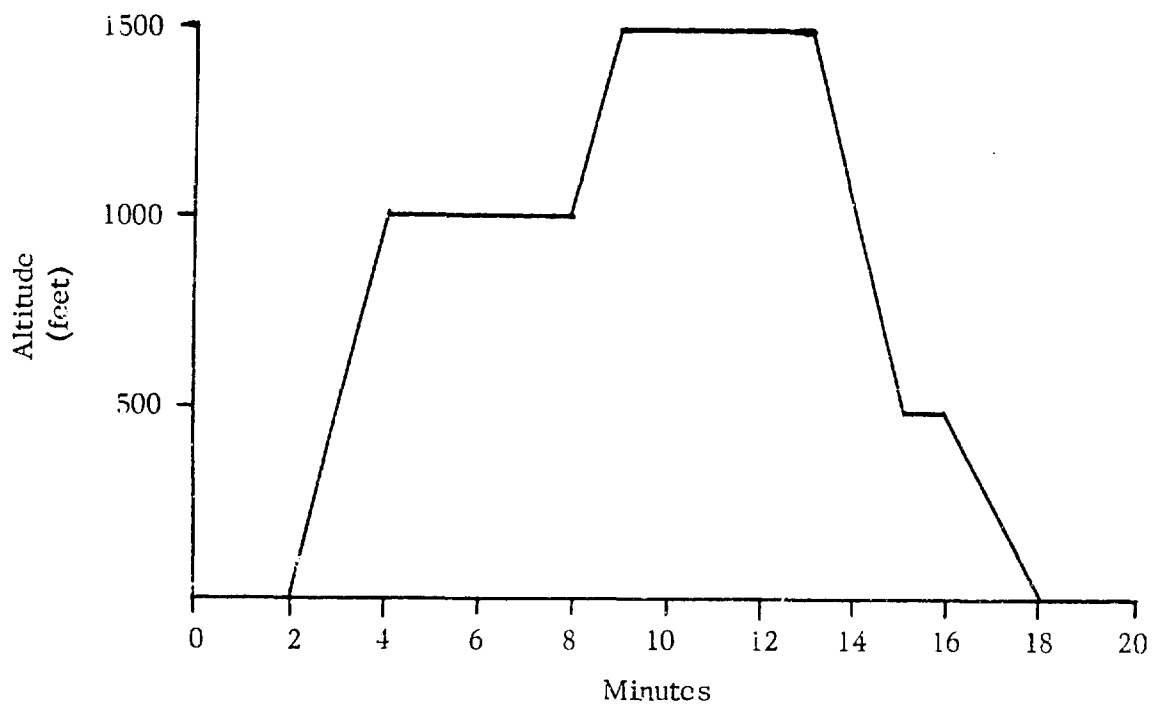


Fig. 1. MISSION PLAN I AND PROFILE

MANEUVER	START	END
Take Off	00:00	
Climb, IFR	00:00	00:03
Cruise, IFR	00:03	00:06
Standard Rate Turn	00:06	00:07
Cruise, IFR	00:07	00:10
Descent, IFR	00:10	00:12
Descending Turn, IFR	00:12	00:13
360° Hovering Turn, VFR	00:13	00:16
Descent	00:16	00:18
Land		00:19

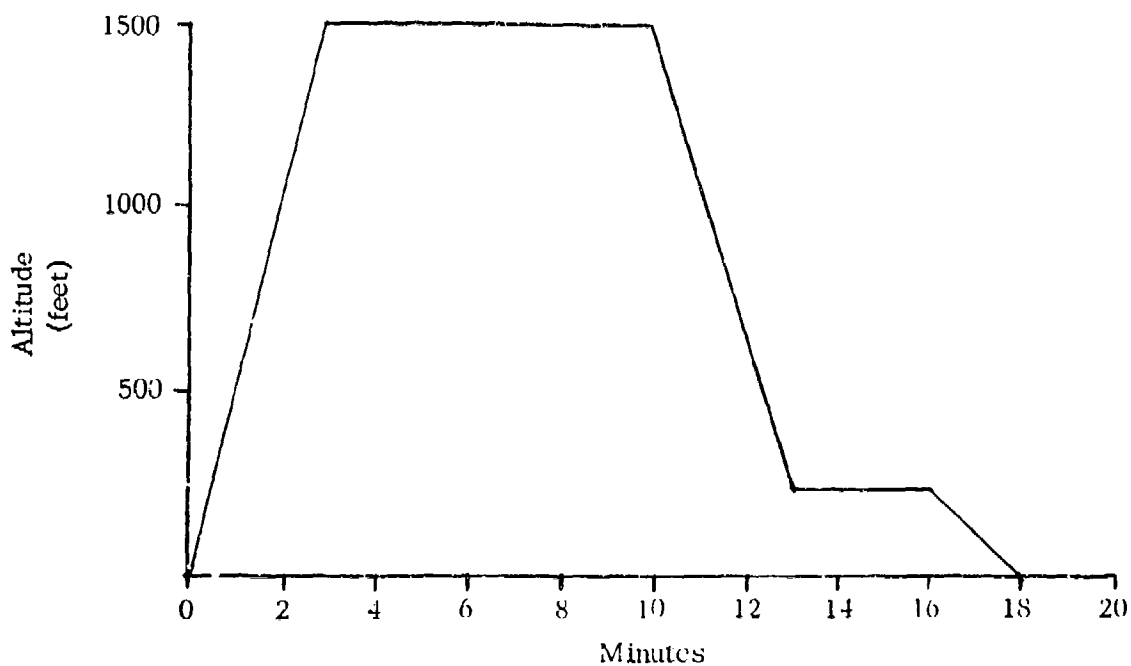


Fig. 2. MISSION PLAN II AND PROFILE

The data given with each table indicates the average number of frames per second used to obtain the data shown. The camera operated at rates of three, four, six and eight frames per second, and the fastest rate possible, consistent with the amount of film available, was used for the recording of the data. The value of Nu, fixations not recorded, fluctuated from a low of 1 percent to a high of 69 percent. The system used to record the eye movements of the subjects is quite accurate when it records eye movements, but an inherent defect does not allow it to record peripheral glances; quite often the subject did not move his head towards the object of his fixations and thus the system would not record the fixation point. This was the one most frequent cause of data losses; other causes were blinks, movement between fixation points at the time of film exposure, bad exposures because of ambient light changes, and some unexplained events.

RESULTS

The tables are presented in the order in which the maneuvers occurred during the flights. The figures given in these tables are the results of this rather limited experiment; their primary value is for use as a basis for further work in the actual flight regime of the helicopter. They do show the experimenter what to expect from an experienced pilot in similar flight conditions, and the problems related indicate areas of concern for the experimenter in this field.

The tables showing the results of the visual maneuvers list fixation points by their location from the center of the pilot's windshield with the legend "Ahead Medium" referring to a point, approximately one-half of the distance to the horizon or the edge of the particular field of view. "Ahead Far" refers to a point approximately three-fourths of the distance to the horizon or the edge of particular field of view, and "Ahead Near" refers to a point approximately one-fourth the distance to the horizon or the edge of the particular field of view. The notation "Left" or "Right" refer to a point equal to one-half of the distance from the center of the pilot's windshield to the designated side of the pilot's windshield. These points are shown graphically in Figures 3 and 4.

The abbreviations for these points as used in the tables are:

A	Ahead, center of pilots windshield
L	Left, one-half the distance to the left edge of pilot's windshield
R	Right, one-half the distance to the right edge of pilot's windshield
F	Far, three-fourths of the distance to the horizon or edge of field of view
M	Medium, one-half of the distance to the horizon or edge of field of view
N	Near, one-fourth of the distance to the horizon or edge of field of view
AL	Ahead Left, one-fourth the distance to the left edge of pilot's windshield
AR	Ahead Right, one-fourth the distance to the right edge of pilot's windshield

FL	Far Left, three-fourths the distance to the left edge of pilot's windshield
FR	Far Right, three-fourths the distance to the right edge of the pilot's windshield
LERn	Left edge of runway
CRn	Center of runway.

Therefore, the notation "ARM,CRn" would indicate a fixation point that is located one-half of the distance to the edge of the field of view to the right by one-fourth the distance from the center to the right edge of the pilot's windshield along the center of the runway.

The tables showing the results of the instrument (IFR) maneuvers list several instrument combinations as fixation points. These listings refer to a fixation point directly between the instruments when two instruments are given, when the number of instruments is greater than two the point is identified by a name. The point called "Engine Group" includes the engine and transmission oil temperature and pressure gages and the fuel quantity and pressure gages. These instruments are those in Figure 5 with the numbers 17, 16, 23, 22, 14 and 13 respectively. These instruments were generally checked as a group during the pilot's periodic check of the engine and power instruments. The point called "Power" refers to a point determined by the intersection of lines from the center of, and through the 6 o'clock position of the Airspeed Indicator, the 5 o'clock position of the Dual Tachometer, and the 3 o'clock position of the Torquemeter Indicator. In Figure 5 these are numbered 9, 19 and 25. The point called "Temp-slip" is located directly below "power" and is adjacent to the Exhaust Gas Temperature Indicator, the Gas Producer Tachometer Indicator and the Turn and Slip Indicator. The numbers 33, 39 and 40 in Figure 5 indicate the location of these instruments. As the name indicates, the peripheral information was gathered from these instruments. The point called "Pocket" refers to a point determined by the intersection of lines from the center of and through the point between 7 and 8 o'clock position of the Altimeter, through the point between the 10 and 11 o'clock position of the Vertical Velocity Indicator, through the point between the 4 and 5 o'clock position of the Attitude Indicator, and through the point between the 1 and 2 o'clock position of the Remote Magnetic Indicator. These instruments are numbered 11, 21, 10 and 27 respectively in Figure 5. The point designated as "Pocket" may well be a peculiarity of the instrument panel arrangement of the UH1B (Fig. 5), but its use provides instrument designers with some pertinent information. A comparison of the mean dwell time (T_d) on this point and the sum of the T_d values for the four separate instruments that make up this point indicates a considerable saving in scan workload when the Pocket is used. These fixation points which list multiple instruments are an example of the pilot's use of peripheral vision to lighten his workload, this becomes apparent when the dwell fractions (n) in the following tables are compared.

AIRCRAFT CENTER LINE

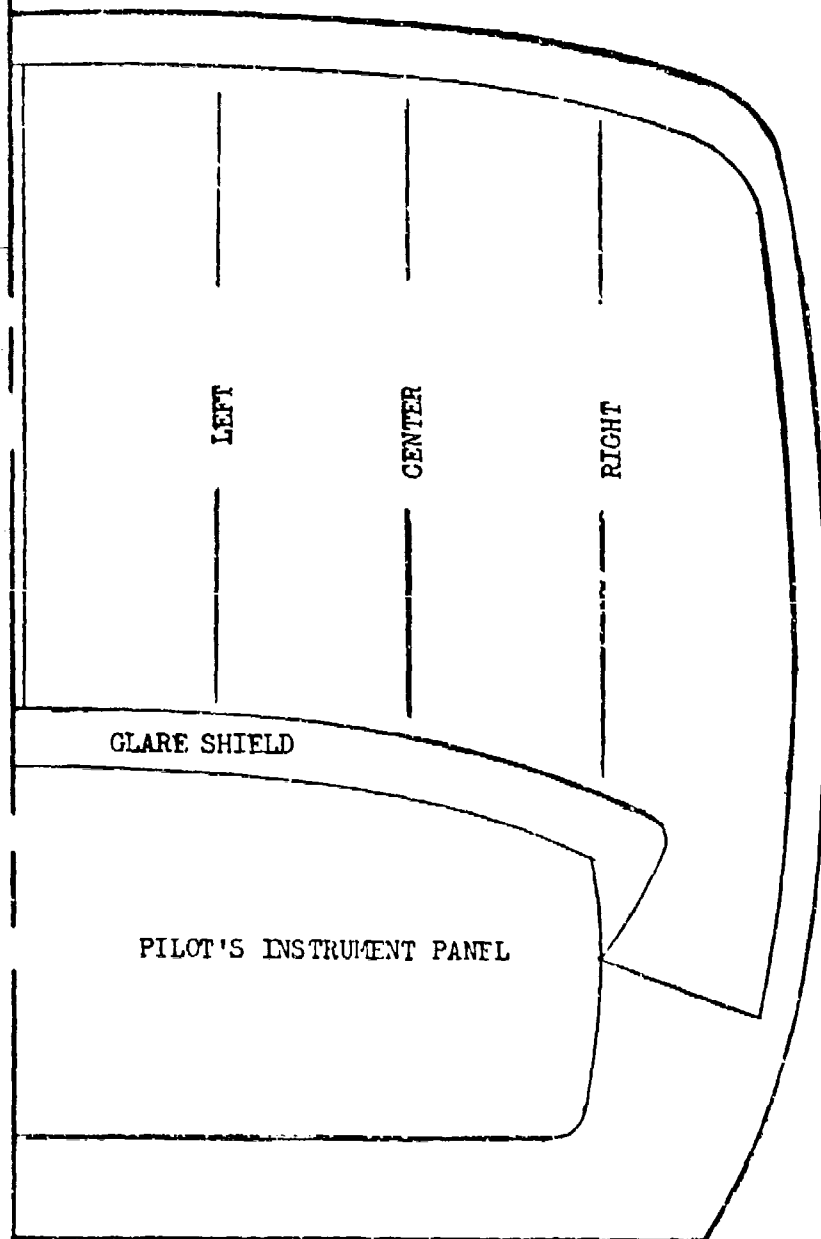


Fig. 3. HORIZONTAL FIELD OF VIEW

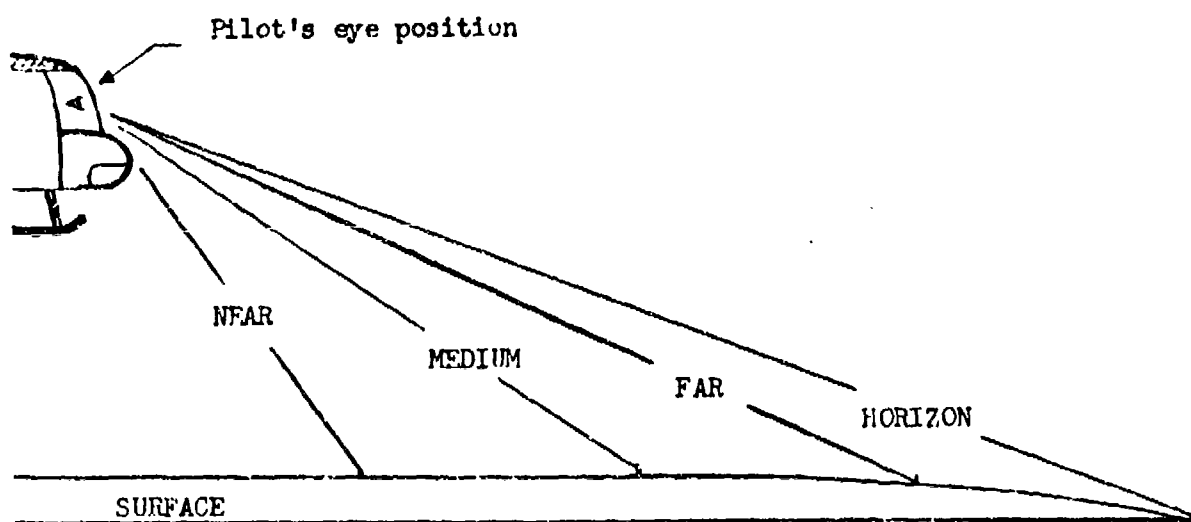
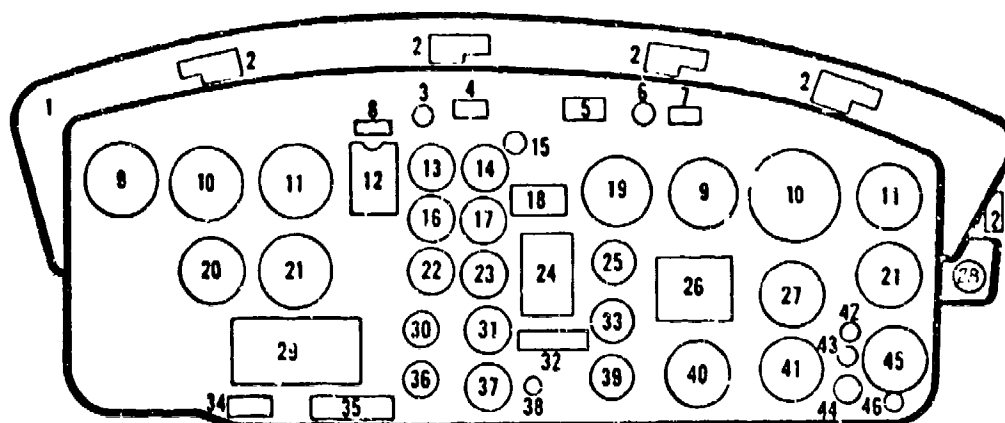


Fig. 4. VERTICAL FIELD OF VIEW



- | | | |
|------------------------------------|--|---------------------------------------|
| 1. Glare Shield | 17. Engine Oil Temperature Indicator | 33. Gas Producer Tachometer Indicator |
| 2. Secondary Lights | 18. Cargo Caution Decal | 34. Engine Installation Decal |
| 3. Engine Air Filter Light | 19. Dual Tachometer | 35. Transmitter Selector Decal |
| 4. Radio Call Designator | 20. Radio Magnetic Indicator | 36. Standby Generator Loadmeter |
| 5. Master Caution Light | 21. Vertical Velocity Indicator | 37. AC Voltmeter |
| 6. RPM Warning Light | 22. Transmission Oil Pressure Indicator | 38. Compass Slaving Switch |
| 7. Fire Detector Test Switch | 23. Transmission Oil Temperature Indicator | 39. Exhaust Gas Temperature Indicator |
| 8. Fire Warning Indicator Light | 24. Pilots Check List | 40. Turn and Slip Indicator |
| 9. Airspeed Indicator | 25. Torquemeter Indicator | 41. Omni Indicator |
| 10. Attitude Indicator | 26. Go-No-Go Take-off Data Placard | 42. Marker Beacon Light |
| 11. Altimeter | 27. Radio-Magnetic Indicator | 43. Marker Beacon Volume Control |
| 12. Compass Correction Card Holder | 28. Standby Compass | 44. Marker Beacon Volume Control |
| 13. Fuel Pressure Indicator | 29. Operating Limits Decal | 45. Clock |
| 14. Fuel Quantity Indicator | 30. Main Generator Loadmeter | 46. Cargo Release Armed Light |
| 15. Fuel Gage Test Switch | 31. DC Voltmeter | |
| 16. Engine Oil Pressure Indicator | 32. Engine Caution Decal | |

Fig. 5. UH-1B INSTRUMENT PANEL

The following abbreviations will be used in the tables of this report:

ATT	Attitude Indicator
PALT	Altimeter
IAS	Airspeed Indicator
VV	Vertical Velocity Indicator
RMI	Remote Magnetic Indicator
SC	Standby Compass
TS	Turn and Slip Indicator
RPM	Dual Tachometer
TQ	Torquemeter Indicator
EGT	Exhaust Gas Temperature Indicator
GPT	Gas Producer Tachometer Indicator
XPT	Cross Pointer
DG	Directional Gyro
GH	Gyro Horizon
HSI	Horizontal Situation Indicator
GS	Glide Slope
ILS	Instrument Landing System Indicator
HI	Heading Indicator.

The hover, in-ground effect (IGE) maneuver was performed both as a visual (VFR) task with the results shown in Table 1 and as an instrument (IFR) task with the results shown in Table 2. The IFR flight came about as a result of a misinterpretation of instructions but it was accomplished with no difficulty and provided a considerable amount of information. Of particular note is the difference in the times spent fixating on the Engine Group and Power point; during the IFR hover 33 percent of the time was spent on these points, while during the VFR hover only 16 percent of the time was expended on the points. The primary fixation points during the VFR hover were Ahead, Medium looking at the left edge of the runway (AM, LERn), Right, Medium looking at the left edge of the runway (RM, LERn), and Left, Medium looking at the left edge of the runway (LM, LERn). These fixation points were approximately 100 feet apart and the helicopter was generally positioned along the center line of the runway.

TABLE 1
VFR Hover IGE

FIXATION POINT	Ni	\overline{Td}	\overline{fs}	n	Ti
RM, CRn	1	.67	.03	.02	.67
RN, CRn	2	.33	.05	.02	.67
RM, LERn	7	.48	.18	.08	3.33
LM, LERn	5	.48	.13	.06	2.33
LN, LERn	1	.33	.03	.01	.33
AM, CRn	1	.67	.03	.02	.67
AN, CRn	2	.50	.05	.03	1.00
AM, LERn	16	1.08	.41	.44	17.33
Power	1	.67	.03	.02	.67
Engine Group	2	1.33	.05	.07	2.67
Nu	28	.33	.72	.24	9.33

Data rate, 3 per second; $T_R = 39$; one run.

TABLE 2
IFR Hover IGE

FIXATION POINT	Ni	\overline{Td}	\overline{fs}	n	Ti
ATT	5	.40	.06	.03	.00
PALT	3	.55	.04	.02	1.67
VV	2	.33	.03	.01	.67
Engine Group	10	1.57	.13	.20	15.67
Power	11	.91	.14	.13	10.00
Pocket	12	1.25	.16	.19	15.00
ATT, IAS	7	.33	.09	.03	2.33
ATT, PALT	11	.94	.14	.13	10.33
Temp-slip	5	.67	.06	.04	3.33
SC	3	.33	.04	.01	1.00
Clock	2	.50	.03	.01	1.00
PALT, VV	2	.67	.03	.02	1.33
SC, VV	7	.33	.09	.03	2.33
PALT, SC	5	.73	.06	.05	3.67
Nu	20	.33	.26	.09	6.67

Data rate, 3 per second; $T_R = 77$; one run.

The 500-foot-per-minute Climb was the first maneuver of Flight Plan II, from Table 3 we see that most of the activity was centered on the Pocket, its component instruments, ATT, PALT, VV and RMI, and the IAS. These instruments account for 55 percent of the fixations during this maneuver.

TABLE 3

Climb IFR

FIXATION POINT	Ni	$\overline{T_d}$	$\overline{f_s}$	n	Ti
ATT	26	.57	.17	.10	14.73
PALT	36	.58	.24	.14	20.74
VV	21	.65	.14	.09	13.69
IAS	31	.47	.20	.10	14.66
RPM	17	.49	.11	.05	8.34
TQ	5	.33	.03	.01	1.67
Engine Group	7	.95	.05	.04	6.67
Power	9	.81	.06	.05	7.33
Pocket	21	.76	.14	.10	15.97
ATT, IAS	5	.49	.03	.01	1.99
PALT, VV, SC	10	.57	.07	.04	5.71
Temp-slip	6	.39	.04	.02	2.33
RMI	5	.53	.03	.02	2.65
SC	3	.33	.02	.01	1.00
Nu	103	.33	.67	.23	34.52

Data rate. 3 per second; $T_R = 152$; two runs.

The Steep Climb, a climb at 1000 feet per minute, was performed both as an IFR and as a VFR maneuver with the only item available for comparison being the Engine Group and Power. It can be seen from the data given in Tables 4 and 5 that the dwell fraction (n) sum for these is .10 in Table 4 the VFR maneuver and .13 in Table 5 the IFR maneuver. Unfortunately a large portion of the out-of-the-cockpit fixations of the visual task were lost for the reasons stated previously. The instrument task data reinforces those of the climb data given in Table 3 and again we find the Pocket, its components and the IAS accounting for 59 percent of the total fixations.

TABLE 4
Steep Climb VFR

FIXATION POINT	Ni	$\overline{T_d}$	$\overline{f_s}$	n	Ti
RM	4	.31	.07	.02	1.25
RN	2	.37	.03	.01	.75
LM	2	.37	.03	.01	.50
LN	1	.50	.02	.01	.50
AM	14	.45	.24	.11	6.25
AN	2	.25	.03	.01	.50
AF	1	.25	.02	--	.25
ARM	4	.50	.07	.03	2.00
ALM	2	.37	.03	.01	.75
Engine Group	5	1.15	.09	.10	5.75
Nu	162	.25	2.79	.69	40.50

Data rate, 4 per second; $T_R = 58$; one run.

TABLE 5
Steep Climb IFR

FIXATION POINT	Ni	$\overline{T_d}$	$\overline{f_s}$	n	Ti
ATT	26	.83	.20	.17	21.67
PALT	23	.90	.18	.16	20.67
VV	10	.53	.08	.04	5.33
IAS	12	.53	.09	.05	6.33
RPM	4	.67	.03	.02	2.67
TQ	2	.33	.02	--	.67
Engine Group	7	.90	.05	.05	6.33
Power	14	.70	.11	.08	10.00
Pocket	18	1.17	.14	.17	21.33
ATT, IAS	6	.83	.05	.04	5.00
ATT, PALT	11	.64	.09	.05	7.00
Temp-slip	3	1.00	.02	.02	3.00
RMI	1	1.00	.01	.01	1.00
SC	8	.70	.06	.04	5.67
Clock, VV	1	.67	.01	--	.67
PALT, VV, SC	10	.83	.08	.07	8.33
Nu	4	.33	.03	.01	1.33

Data rate, 3 per second; $T_R = 127$; one run.

The IFR Climb incorporates a 360-degree turn which probably accounts for the greater amount of time spent on the direction-indicating instruments as compared to their use during the regular IFR climbs.

Both of the mission plans called for an instrument Cruise leg after level off and the data from these legs are given in Table 6. These data reflect the fixation points on more than 2200 frames, and from them it can be determined that the primary flight instruments, ATT, PALT, VV and IAS accounted for 36 percent of the fixation points. The Pocket and RMI accounted for 14 percent of the points as did the Engine Group and Power for a grand total of 64 percent of the fixations among these fixation points. The fixation points lost for various causes during the cruise legs amounted to an unfortunate 22 percent of the total.

TABLE 6

Cruise IFR

FIXATION POINT	Ni	\overline{Td}	\overline{fs}	n	Ti
ATT	130	.59	.21	.12	77.34
PALT	149	.57	.24	.14	85.46
VV	46	.43	.07	.03	19.63
IAS	89	.46	.14	.07	40.72
RPM	14	.35	.02	.01	4.95
TQ	2	.33	--	--	.66
Engine Group	53	.87	.08	.07	46.09
Power	71	.61	.11	.07	43.12
Pocket	92	.82	.15	.12	75.14
ATT, IAS	23	.60	.04	.02	13.71
ATT, PALT	39	.69	.06	.04	26.91
Temp-slip	16	.58	.02	.01	9.34
RMI	19	.62	.03	.02	11.85
SC	32	.45	.05	.02	14.45
TS	2	.33	--	--	.66
Clock	2	.67	--	--	1.34
RPM, IAS	4	.33	.01	--	1.33
PALT, VV	4	.50	.01	--	2.00
SC, VV	2	.67	--	--	1.34
PALT, VV, SC	4	.75	.01	--	3.00
Nu	504	.28	.81	.22	138.96

Data rate, 3.6 per second; $T_R = 618$; four runs.

An integral part of the cruise leg was the 180-degree Standard Rate Turn (three degrees per second). The data from three turns are shown in Table 7. As would be expected, there was a somewhat greater percentage of fixations made on the RMI than usual and the mean dwell time was also quite large, 1.07 seconds. This was almost double the \bar{T}_d value for the RMI during the cruise maneuver. Again, the Pocket, its associated instruments and the IAS accounted for most of the fixation time, 63 percent.

TABLE 7
180-Degree Turn IFR

FIXATION POINT	Ni	\bar{T}_d	\bar{f}_s	n	Ti
ATT	42	.58	.27	.16	24.52
PALT	39	.62	.27	.16	24.33
VV	10	.62	.06	.04	6.17
IAS	15	.51	.10	.05	7.67
Engine Group	13	.67	.08	.06	8.67
Power	13	.54	.08	.04	6.70
Pocket	27	.75	.17	.13	20.15
ATT, IAS	3	1.11	.02	.02	3.33
RMI	12	1.07	.08	.08	12.83
TS	2	.50	.01	.01	1.00
Clock	1	.33	.01	--	.33
SC, VV	14	.58	.09	.05	8.13
Nu	94	.33	.61	.18	28.51

Data rate, 3 per second; $T_R = 154$; three runs.

The cruise legs were followed by a Steep Approach with a descent rate of approximately 800 feet per minute. Table 8 presents the data from this maneuver. At this point the pilots were approximately 17 minutes into a 20 to 25-minute mission and the general instrument-usage pattern had changed very slightly from maneuver to maneuver. The Pocket, its associated group and the IAS accounted for 69 percent of the fixation time and the Engine Group and Power accounted for 14 percent of the time. It is interesting to note that for all the maneuvers from the climb (Table 3) through the steep approach (Table 8) the overall average for the fixation time on the Engine Group and Power was 13 percent.

TABLE 8
Steep Approach IFR

FIXATION POINT	N	\bar{T}_d	\bar{f}_s	n	\bar{T}_i
ATT	48	.71	.27	.19	33.90
PALT	57	.59	.32	.19	33.65
VV	27	.57	.15	.09	15.35
IAS	28	.49	.16	.08	13.72
RPM	8	.29	.04	.01	2.31
Engine Group	16	.82	.09	.07	13.20
Power	19	.55	.11	.06	10.45
Pocket	36	.84	.17	.14	25.15
ATT, IAS	19	.64	.11	.07	12.08
ATT, PALT	6	.52	.03	.02	3.12
RMI	1	.87	.01	--	.87
SC	4	.28	.02	.01	1.12
TS	1	.50	.01	--	.50
SC, VV	6	.46	.01	.02	2.75
Nu	69	.16	.38	.06	10.83

Data rate, 6.36 per second; $T_R = 179$; two runs.

One of the mission plans called for a 180-degree Descending Standard Rate Turn at the end of the approach. The data reported in Table 9 are somewhat different than that from previous maneuvers in that the time spent on the Engine Group and Power fixation points was half of what it had been during the previous maneuvers and the time spent on the Attitude Indicator alone was 30 percent greater than it had been on any of the other maneuvers. The Pocket, its associated instruments and the IAS accounted for 82 percent of the fixation time.

TABLE 9
180-Degree Descending Turn IFR

FIXATION POINT	Ni	$\overline{T_d}$	$\overline{f_s}$	n	Ti
ATT	31	.84	.36	.30	26.17
PALT	18	.72	.21	.15	13.00
VV	12	.72	.14	.10	8.67
IAS	13	.55	.15	.08	7.17
Engine Group	5	.53	.06	.02	2.17
Power	5	.60	.06	.03	3.00
Pocket	9	1.11	.10	.12	10.00
ATT, IAS	8	.69	.09	.06	5.50
RMI	3	.33	.03	.01	1.00
TS	2	1.50	.02	.03	3.00
IAS, RPM	2	.25	.02	.01	.50
Nu	35	.17	.41	.07	5.82

Data rate, 6 per second; $T_R = 86$; one run.

The 360-degree Hovering Turn was performed over a small island in a bay at an altitude of 200 feet and was a VFR maneuver. The fixation points and times reflect the fact that part of the time the pilot was able to use the shoreline as a reference and part of the time he had to use his instruments. A comparison of these data as shown in Table 10 with those shown in Tables 1 and 2 indicates that the percentage of time spent fixating on the Engine Group and Power was essentially the same for Tables 1 and 10, (different pilots), and again the pilots had a definite prime visual reference point, Ahead Medium for Table 1 and Right and Far Right Medium for Table 10.

TABLE 10
360-Degree Hovering Turn OGE

FIXATION POINT	Ni	$\overline{T_d}$	$\overline{f_s}$	n	Ti
ATT	8	.61	.09	.06	4.89
PALT	13	.48	.15	.07	6.25
VV	1	.25	.12	--	.25
IAS	9	.61	.10	.06	5.51
RPM	5	.37	.06	.02	1.88
Engine Group	5	.37	.06	.02	1.88
Power	5	.45	.06	.03	2.25
Pocket	2	.25	.02	.01	.50
ATT, IAS	2	.25	.02	.01	.50
ATT, PALT	6	1.35	.07	.09	8.13
RM	3	1.42	.03	.05	4.25
RN	18	.78	.21	.16	14.00
RF	3	.29	.03	.01	.87
LN	4	.44	.05	.02	1.75
LF	2	1.19	.02	.03	2.37
AM	2	.44	.02	.01	.87
AN	9	.32	.10	.03	2.87
FRM	21	.67	.24	.16	14.13
FRN	1	.87	.01	.01	.87
Nu	96	.12	1.11	.14	11.98

Data rate, 8 per second; $T_R = 86$; one run.

Mission Plan I called for an IFR Hover at an altitude of 500 feet. The data from this maneuver are shown in Table 11. An item of interest was the difference in mean dwell time ($\overline{T_d}$) on the Engine Group and Power that was associated with the hover maneuvers done out of ground effect (OGE) and the maneuver done in ground effect (IGE) hover maneuvers had a combined $\overline{T_d}$ for Table 1 of 1.11 and 1.21 for Table 2 while the OGE hover maneuvers showed values of .41 for Tables 10 and .60 for Table 11.

TABLE 11
IFR Hover OGE

FIXATION POINT	Ni	$\overline{T_d}$	$\overline{f_s}$	n	Ti
ATT	23	.68	.34	.23	15.67
PALT	24	.57	.36	.20	13.67
VV	9	.41	.13	.05	3.67
IAS	10	.47	.15	.07	4.67
Engine Group	4	.67	.06	.04	2.67
Power	15	.58	.22	.13	8.67
Pocket	12	.83	.18	.15	10.00
ATT, IAS	2	.33	.03	.01	.67
Temp-slip	3	.89	.04	.04	2.67
Nu	14	.33	.21	.07	4.64

Data rate, 3 per second ; $T_R = 67$; one run.

One other point for comparison of the data from the two IFR hover maneuvers was the n and \bar{T}_d values for the primary flight instruments, ATT, VV, PALT, IAS and RMI. Their combined n values for the IGE hover was .51 or 51 percent of the run time and the \bar{T}_d value was .73, while for the OGE hover the combined n value was .72 with a \bar{T}_d of .60. The figures indicate that the pilots spent a greater amount of the run time (T_R) looking at these instruments but with a shorter time for each fixation when flying the OGE hover than they did when flying the IGE hover. The final scheduled maneuver was the vertical descent; the data from this maneuver are given in Table 12.

TABLE 12
Vertical Descent

FIXATION POINT	N_i	\bar{T}_d	\bar{f}_s	n	T_i
ATT	13	.75	.17	.12	9.70
PALT	14	.53	.18	.10	7.41
VV	9	.57	.11	.07	5.17
IAS	14	.65	.18	.12	9.05
RPM	1	.33	.01	--	.33
Engine Group	3	.80	.04	.03	2.42
Power	5	.38	.06	.02	1.88
Pocket	14	.54	.18	.10	7.50
ATT, IAS	3	.87	.04	.03	2.61
ATT, PALT	1	.33	.01	--	.33
Temp-slip	3	.33	.04	.01	1.00
RMI	4	.67	.05	.03	2.68
SC	1	.67	.01	.01	.67
PALT, VV	3	.39	.04	.01	1.17
RN	6	.75	.08	.06	4.48
LN	2	.46	.03	.01	.92
AN	8	.75	.10	.08	6.04
AF	6	.50	.08	.04	3.00
FRN	1	.62	.01	.01	.62
Nu	43	.26	.55	.14	11.02

Data rate, 3.8 per second ; $T_R = 78$; two runs.

Two additional legs were flown to utilize film which remained when the scheduled mission was accomplished. One of these legs was a three-minute low-level cruise done on instruments at an altitude of 350 feet. The data are given in Table 13 and do not differ greatly from those shown in Table 6, which concerns cruise flight at 1000 feet or higher.

TABLE 13
Low-Level Cruise IFR

FIXATION POINT	Ni	\overline{Td}	\overline{fs}	\overline{r}	Ti
ATT	44	.62	.25	.14	24.25
PALT	29	.49	.17	.07	12.79
VV	18	.50	.10	.05	9.00
IAS	26	.40	.15	.06	10.34
Engine Group	17	.78	.10	.08	13.34
Power	30	.44	.17	.08	13.34
Pocket	40	.76	.23	.17	30.34
ATT, IAS	21	.44	.12	.05	9.34
PALT, VV	23	.52	.13	.07	13.00
Temp-slip	9	.59	.05	.03	5.34
RMI	20	.61	.11	.07	12.34
TS	1	.33	--	--	.33
Clock	5	.33	.03	.01	1.67

Data rate, 3 per second ; $T_R = 173$; one run.

The other maneuver was a short leg of terrain following with the data shown in Table 14. These data indicated that the pilot, who was seated in the right seat, spent 49 percent of his time fixating on points to the right of his center line, 23 percent on points to the left of his center line, and 12 percent on points located on his center line. In terms of distance ahead of his aircraft, the data showed that 53 percent of the time was spent at a point approximately one-half the distance to the horizon and 31 percent was spent at a point approximately one-quarter the distance to the horizon. The remaining time was divided between the Engine Group at 2 percent and lost fixations at 13 percent. While this information may be biased by the relatively flat terrain and the pilot's familiarity with the terrain, it is still of value and can be used for comparison with future data collected during terrain-following tasks at speeds of 40 to 60 KIAS.

TABLE 14
Terrain Following

FIXATION POINT	Ni	\bar{T}_d	\bar{f}_s	n	Ti
RM	12	.94	.17	.14	13.25
RN	5	1.45	.07	.10	7.25
LM	6	.37	.08	.03	2.25
LN	11	.95	.15	.15	10.75
AM	15	.25	.21	.09	6.75
AN	3	.67	.04	.03	2.00
ARM	9	.44	.13	.06	4.00
ARN	2	.37	.03	.01	.75
ALM	7	.37	.10	.03	2.50
FRM	11	1.40	.15	.18	13.00
FLN	1	1.00	.01	.01	1.00
Engine Group	2	.63	.03	.02	1.25
Nu	36	.25	.50	.13	9.00

Data rate, 4 per second ; $T_R = 72$; one run.

Link Values

The transitions between the various instruments is a measure of eye movements which has been studied by many researchers. Milton et al considered these to be an indicator of the goodness of an instrument-panel arrangement. These values, usually called "link values" between two instruments or fixation points i and j , can be expressed as:

$$q_{ij} = \sum_{k=1}^N q_{ijk}$$

where N = the number of transitions from i to j .

$$q_{ij} = \sum_{k=1}^M q_{jik}$$

where M = the number of transitions from j to i . Therefore q_{ij} and q_{ji} are one-way link values and the total activity between fixation points i and j can be expressed as:

$$Q_{ij} = q_{ij} + q_{ji}$$

The value Q_{ij} will be used in the text of this report for the maneuvers discussed and the two-way link values can be found in Appendix B.

The tables given in this section show the Q_{ij} values greater than 4 percent of the total link values for the maneuver. Table 15, which concerns VFR Hover IGE, indicates that the greatest amount of activity was between the Ahead Medium (AM) and the Ahead Right Medium (ARM) fixation points on the left edge of the runway (LERn), followed closely by the Ahead Medium and the Ahead Left Medium (ALM) on the left edge of the runway area. This finding indicates that the pilot was scanning up and down the left edge of the runway to establish a reference which would enable him to hold his position. Actually, 92 percent of the link values concerned with this maneuver were involved with this particular terrain feature.

TABLE 15

VFR Hover IGE

LINK	PERCENTAGE VALUE
AM, LERn; ALM, LERn	18
AM, LERn; ARM, LERn	22
ALM, LERn; ARM, LERn	11
ARM, LERn; Cockpit	11
ARN, CRn; AM, LERn	11
AM, LERn; AN, LERn	7
AM, LERn; Cockpit	7

Table 16, the data for the IFR Hover IGE, shows that the major activity is between the Attitude Indicator, IAS fixation point and the Power fixation point, and between the Engine Group and Power points. This concentration of activity appears to verify the pilot's expressed (1) concern about his attitude and available power when performing the hover maneuver.

TABLE 16
IFR Hover IGE

LINK	PERCENTAGE VALUE
ATT, IAS; Power	10
Engine Group; Power	8
ATT; Pocket	8
ATT; VV	5
ATT; PALT, SC	5
PALT; VV, SC	5

Table 17 indicates that during the climb maneuver the pilot's main concern was his attitude and rate of climb as shown by the link values between the instruments providing this information. The rest of his attention was centered on attitude, airspeed and power available.

TABLE 17
Climb

LINK	PERCENTAGE VALUE
PALT; VV	12
IAS; RPM	9
PALT; ATT	8
IAS; ATT	7
PALT; Pocket	5
VV; Pocket	5

When the rate of climb was increased and the angle of the climb approached the vertical, the points of interest shifted to the attitude of the aircraft as seen in Table 18. The rather prominent position of the compass in this table was an artifact of this particular mission which required a turn during the steep climb to clear a restricted area. The steep climb was also performed as a visual maneuver and the link values are given in Table 19 which indicate that the pilot did considerable cross checking from visual fixation points to cockpit fixation points. These exact cockpit fixation points were not recorded because of previously enumerated system deficiencies. The general area of fixation was ahead of the aircraft at a point half the distance to the horizon.

TABLE 18
IFR Steep Climb

LINKS	PERCENTAGE VALUE
ATT; Pocket	12
ATT; PALT	10
Pocket; SC	10
Pocket; PALT	9
ATT; IAS	8
ATT; SC	8
RPM; Engine Group	7
Pocket; Power	6
RPM; IAS	5

TABLE 19
VFR Steep Climb

LINKS	PERCENTAGE VALUE
AM; Cockpit	22
AM; ALM	13
AM; ARM	9
ARM; Cockpit	9
ARM; RN	9
AM; RM	9

During the IFR Cruise portion of the missions (Table 20), the major activity was between the attitude indicator and the altimeter, with a lesser amount of interest concerned with the airspeed and the engine instruments and power output indicators. When the pilots performed the 180-degree Standard Rate Turn (Table 21) during the cruise leg the scan-pattern emphasis changed very slightly; the turn-and-slip indicator and the remote magnetic indicator replaced the engine condition and power-output indicators as fixation points for link activity.

TABLE 20

Cruise IFR

LINKS	PERCENTAGE VALUE
ATT; PALT	16
Pocket; PALT	9
ATT; IAS	8
Power; Engine Group	8
Power; IAS	5
SC; PALT	5
ATT; PALT; PALT	5
ATT; Pocket	5
PALT; VV	5

TABLE 21

180-Degree Turn IFR

LINKS	PERCENTAGE VALUE
ATT; PALT	15
Pocket; PALT	9
ATT; IAS	5
TS, RMI; ATT	5

Table 22 gives the link values for the Steep Approach maneuver and, as would be hypothesized, the vertical velocity, altimeter and attitude indicator were the prime traffic points, with the airspeed and power output also drawing a share of the pilot's attention.

TABLE 22
Steep Approach IFR

LINKS	PERCENTAGE VALUE
ATT; PALT	14
VV; PALT	12
ATT; Pocket	8
ATT; IAS	7
Power; IAS	5
Pocket; VV	5

The 180-degree Descending Turn (Table 23) had a link pattern quite similar to that of the Steep Approach, but with more link values of 5 percent and greater. This finding indicates a reduced amount of wide-scanning activity and a greater concentration of activity on the listed fixation points.

TABLE 23
180-Degree Descending Turn IFR

LINKS	PERCENTAGE VALUE
ATT; PALT	24
PALT; VV	8
ATT; IAS	7
IAS; Power	7
ATT; VV	6
Pocket; VV	5
Pocket; ATT	5
IAS; ATT	5

Table 24 shows the four link values from a total of 46 that made up 5 percent or more of the total transitions which occurred during the 360 degree Hovering Turn OGE. These data showed a large number of one and two transition value links.

TABLE 24
360-Degree Hovering Turn OGE

LINKS	PERCENTAGE VALUE
IAS; Power	5
PALT; RN	10
FRN; RN	11
AN; RN	9

In almost direct contrast was the Hover OGE data shown in Table 25. Eighty-one percent of the total link values are in the table, while the remaining 19 percent of the link values represent 11 different links.

TABLE 25
IFR Hover OGE

LINKS	PERCENTAGE VALUE
ATT; PALT	26
PALT; VV	10
IAS; Power	10
PALT; Pocket	9
Pocket; ATT	8
IAS; ATT	8
Engine Group; Power	6
Pocket; VV	6

A comparison of the data from the two IFR Hover maneuvers shows the same links are present in both tables, but the amount of scan workload or scan activity was much greater for the IGE maneuver. This increase can be determined by noting the sums of the percentage value for each table. The links for the vertical descent maneuver (Table 26) totaled 46, but only three accounted for 5 percent or more of the transitions; the majority of the links again were of the one or two transitions value. This condition was the same as encountered in the 360-degree Hovering Turn OGE and also as shown in Table 27, the data for low-level cruise where only six of 46 links are of the 5 percent or greater value.

TABLE 26
Vertical Descent

LINKS	PERCENTAGE VALUE
ATT; PALT	6
IAS; Power	6
PALT; VV	5

A comparison of the percentage values and links from Table 20, Cruise, and those of the Low-Level Cruise shown in Table 27 indicate similar scan patterns for both maneuvers. Table 28 presents the data from the short Terrain-Following leg. This maneuver had seven of 36 percentage values 5 percent or greater, while the other comparable maneuver, VFR Hover IGE, had seven of its 10 percentage values 5 percent or greater. This increased scanning activity could be considered a measure of the difficulty of the Terrain-Following task.

TABLE 27
Low-Level Cruise IFR

LINKS	PERCENTAGE VALUE
ATT; PALT, VV	7
IAS; Power	6
Engine Instruments; Power	6
ATT; PALT	5
PALT; Pocket	5
Pocket; PALT, VV	5

TABLE 28

Terrain Following VFR

LINKS	PERCENTAGE VALUE
FRM; RM	10
AM; ARM	7
ALN; LN	6
AM; LN	5
AM; RN	5
AN; RN	5
ARM; RM	5

DISCUSSION

Data from the following studies were converted to the standard form of this report and then used to construct the comparison tables in this section:

CODE	REF. NO.	STUDY TITLE	AIRCRAFT
M-1	9	Comparative Study of Pilot Fatigue Using Standard Army Air Force and British Instrument Panels.	PBY-5A
JMF-1	6	Eye Fixations of Aircraft Pilots, I	NH-1
MJF-2	10	Eye Fixations of Aircraft Pilots, II (ILAS)	C-45
FJM-3	3	Eye Fixations of Aircraft Pilots, III (GCA)	C-45
JMF-4	7	Eye Fixations of Aircraft Pilots, IV (IFR)	C-45
MJF-5	11	Eye Fixations of Aircraft Pilots, V (IFR & VFR)	C-45
MMC-6	12	Eye Fixations of Aircraft Pilots, VI (ILAS)	C-45
MMC-7	13	Eye Fixations of Aircraft Pilots, VII (GCA)	C-45
MW-8	14	Eye Fixations of Aircraft Pilots, VIII (Zero-Reader)	T-33
CMM-9	2	Eye Fixations of Aircraft Pilots, IX (IFR)	C-45
GO-1	5	Pilot Eye Fixations While Flying Selected Maneuvers Using Two Instrument Panels.	F-102 Simulator
WK-1	16	The Measurement and Analysis of Pilot Scanning and Control Behavior During Simulated Instrument Approaches.	DC-8 Simulator
SCW-1	15	Human Visual Sampling Processes: A Simulation Validation Study.	C-11B Simulator
L-1	8	Airline Pilots' Eye Movements During Take-Off and Landing in Visual Meteorological Conditions.	B-707 L-188
B-1	1	Analysis of Pilots' Eye Movements During Helicopter Flight.	UH-1B
G-1	4	The Effects of Training in a Simple Generalized Contact Trainer	A-4-2N Simulator

Before any comparisons are attempted, some explanation of the performance and configuration of the aircraft used and simulated in the listed studies is necessary.

The PBV-5A is a high-wing, twin-engined amphibian powered by R-1830 engines and capable of carrying heavy loads for long distances. The NH-1 (Howard DGA-15) is a high-wing, single-engine, five-passenger, fixed conventional-gear aircraft powered by a 450 HP R-985 engine. The C-45 (Beech 18) is a low-wing, twin-engine, nine-passenger, retractable conventional-gear aircraft powered by two R-985 engines. This aircraft has an approach speed of 120 KIAS and a cruise speed of approximately 140 KIAS.

The T-33 is a single-jet, low-wing, two-place, retractable tricycle-gear aircraft. This aircraft has an approach speed of 130 KIAS. The DC-8 and the B-707 are low-wing, four-jet, 100-plus passenger, retractable tricycle-gear aircraft. These aircraft have approach speeds of approximately 135 KIAS.

The C-11 is a Link simulator which had been modified for the reported experiment. It had flight characteristics similar to the T-33.

The L-188 (Electra) is a low-wing, four-turboprop, 50-plus passenger, retractable tricycle-gear aircraft. This aircraft has an approach speed of approximately 135 KIAS.

The F-102 is a single-jet, delta-wing, two-place, retractable tricycle-gear aircraft. This aircraft has an approach speed of approximately 250 KIAS.

The UH-1B is a single-jet, single two-bladed rotor, five-place, skid-gear helicopter. It has an approach speed of 40 KIAS, a cruise speed of 60 to 80 KIAS and a maximum speed in excess of 100 KIAS.

The A-4 is a single-jet, low-wing, single-place, retractable tricycle-gear aircraft. It has an approach speed greater than the T-33 and less than the F-102.

The approach maneuver was documented in the majority of the studies cited and therefore offered the most information for comparison of Dwell Fraction (n , the percentage of the total maneuver time that was spent on the particular fixation point), and Mean Dwell Time (\bar{T}_d). The approach maneuver was not flown in the same manner across the studies nor were the speeds the same, but the effects of specialized instrumentation and techniques were apparent in the values of n and \bar{T}_d . The UH-1B was the only aircraft which did not use any special instruments or techniques for this maneuver. Tables 29 and 30 provide the values of n and \bar{T}_d .

The ' n ' values from studies JMF-4 (7), GO-1 High (5) and B-1 (1) should indicate the differences in eye-movement behavior of pilots flying drastically different aircraft during an approach-profile flight. We are essentially looking at a slow, stable fixed-wing twin, a medium-size helicopter, and a supersonic delta-wing jet. The mean usage of the Attitude Indicator was 21 percent \pm 2 and the percentage spread for the Vertical Velocity was also small, but the n values for the remaining instrument all showed some drastic value differences. The B-1 (1) and GO-1 High (5) studies were fairly close for the values of Altitude and Airspeed. The apparent lack of attention to directional control in the B-1 (1) study was an artifact of the flight area in that there was no need for maintaining a given heading during this maneuver.

The values shown for FJM-3 (3), MMC-7 Day (13) and MMC-7 Night (13) were obtained during Ground-Controlled Approaches (GCA) with the difference in instrument panel arrangement the primary variable. Neither panel was arranged in accordance with present standards.

TABLE 29

Approach Maneuver -- Dwell Fraction "n"

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	HSI	DG	RMI	TS	INST	RPM	EGT
MJF-2 (C-45)		.15	.02	.02	.10	.41		.25	.01	.02			
FJM-3 (C-45)		.19	.03	.05	.17	--		.49	.02	.04			
JMF-4 (C-45)		.22	.07	.08	.24	--		.21	.02	.12			
MJF-6 (C-45) DAY		.11	.02	.05	.07	.45		.20	--	.04			
MJF-6 (C-45) NIGHT		.06	.02	.05	.08	.56		.18	--	.02			
MMC-7 (C-45) DAY		.13	.03	.16	.11	--		.46	--	.05			
MMC-7 (C-45) NIGHT		.08	.04	.19	.14	.01		.48	--	.02			
MW-8 (T-33)		.13	.01	.02	.09	.64*		.01	.02	--	.04	.01	
B-1 (UH-1B)		.19	.19	.09	.08	--		.01	--	.07	.01	--	
GO-1 (F-102 Simulator) LOW		.15	.06	.07	.07	.22							
GO-1 (F-102 Simulator) HIGH		.23	.14	.06	.12	.03		.17					
WK-1 (DC-8 Simulator)		.44	.02	.04	.02	.47		.21					
SCW-1 (C-11B Simulator)		.28	.07	.13	.07	.23							
* ZERO READER													

TABLE 30

Approach Maneuver -- Mean Dwell Time "Td"

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	HSI	DC	TS	INST	RPM	EGT
MJF-2 (C-45)		.52	.38	.39	.38	.86	.56	.34	.79			
FJM-3 (C-45)		.56	.39	.47	.57	--	.90	.36	.88			
JMF-4 (C-45)		.54	.48	.49	.67	--	.54	--	1.25			
MJF-6 (C-45) DAY		.37	.38	.39	.49	.76	.54	--	.89			
MJF-6 (C-45) NIGHT		.40	.44	.53	.55	1.23	.66	--	.89			
MMC-7 (C-45) DAY		.49	.36	.98	.54	.18	.98	.29	1.13			
MMC-7 (C-45) NIGHT		.54	.43	.69	.70	.36	.24	.18	1.00			
MW-8 (T-33)		.48	.42	.45	.52	1.29 [*]	.50	.70	--	.66	.48	
B-1 (UH-1B)		.71	.59	.57	.49	--	.87	.50	.82	.29		
GO-1 (F-102 Simulator) LOW		.36	.47	.38	.45	.30	.52					
GO-1 (F-102 Simulator) HIGH		.42	.60	.42	.48	.32	.50					
WK-1 (DC-8 Simulator)		.85	.43	.43	.70	.96	--					
#ZERO READER												

The remaining data reflect information gained from studies of Instrument Low Approach Systems (ILAS) flown by different types of aircraft using different types of indicators.

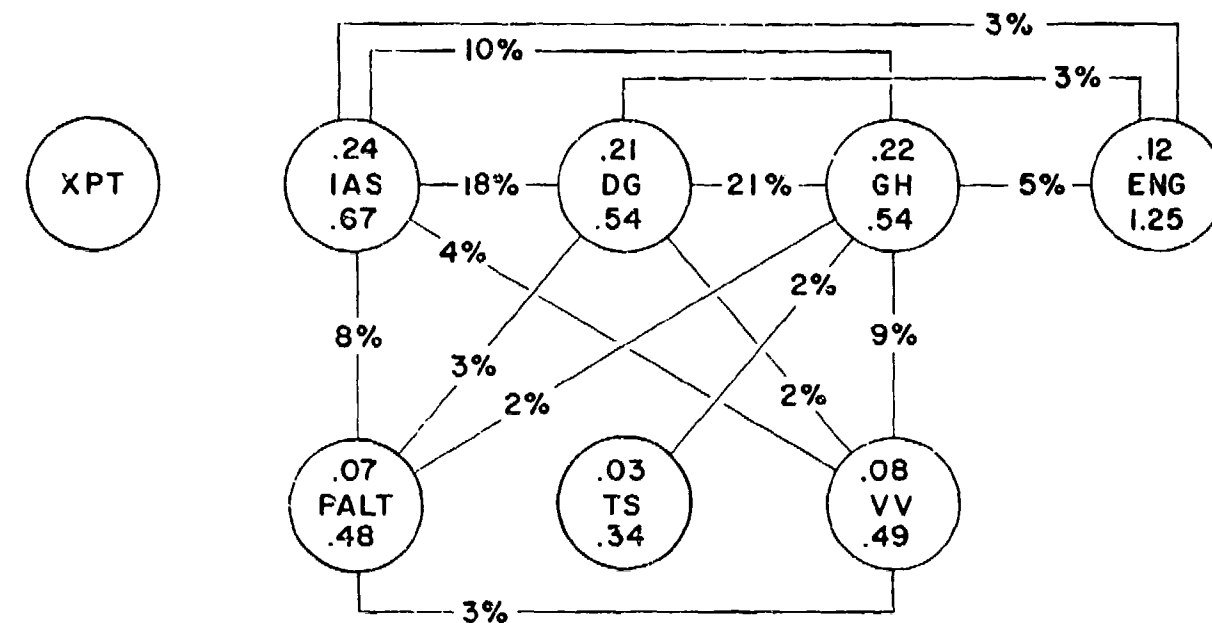
Table 30 gives the values of the mean-time spent looking at the instrument during a fixation. For the three approach profiles the mean values of \bar{T}_d for the flight instruments was $.56 \pm .02$ seconds and approximately one second for the engine instruments. The helicopter pilots fixated considerably longer on the Attitude Indicator and the Remote Magnetic Indicator than did the C-45 or F-102 pilots. The Mean Dwell Time for the RMI seemed to indicate that although the helicopter pilots did not look at this instrument very often during this maneuver they did spend considerable time looking at when they did fixate.

When a specialized instrument was provided for the pilot's use and the testing was concerned with tasks involving this instrument, the pilots spent a larger proportion of their time using and looking at the instrument. This was shown by the values of n and \bar{T}_d for the HSI/XPT on Tables 29 and 30 for studies MJF-2 (10), MJF-6 (12), MW-8 (14), GO-1 Low (5) and WK-1 (16).

When the link values are displayed graphically, it is possible to observe the changes in scanning behavior caused by different displays, aircraft flight demands and pilot techniques. Figure 6 presents the scanning patterns that were followed by the UH-1B pilots during a steep approach and those of the C-45 (7) pilots flying a constant heading descent/approach. Each instrument is identified and is shown in its position relative to the actual location in the aircraft instrument panel. The link values were the two-way sum of the "to" and "from" links, link values between the instruments. The numbers at the top of the instruments are the values which were computed as " n ," dwell fraction, and the numbers at the bottom of the instruments are the values which were computed as " \bar{T}_d ," mean dwell time. The UH-1B data reporting differed from those of the other studies in that fixation points other than instruments were recorded and identified. This is an important change because it indicated to the reader those instruments the pilot was using his peripheral vision to monitor and because it showed how peripheral vision was used to lessen the scanning workload. The fixation points Pocket, Power and Temp-slip were the most frequently used. The scanning workload reduction is quite apparent when the values for the Directional Gyro DG, ATT, VV and PALT for the C-45 are compared with those of RMI, ATT, VV, PALT and Pocket (the point which includes these four instruments). The "standard" instrument arrangement of the UH-1B also aided in the reduction of the scanning workload.

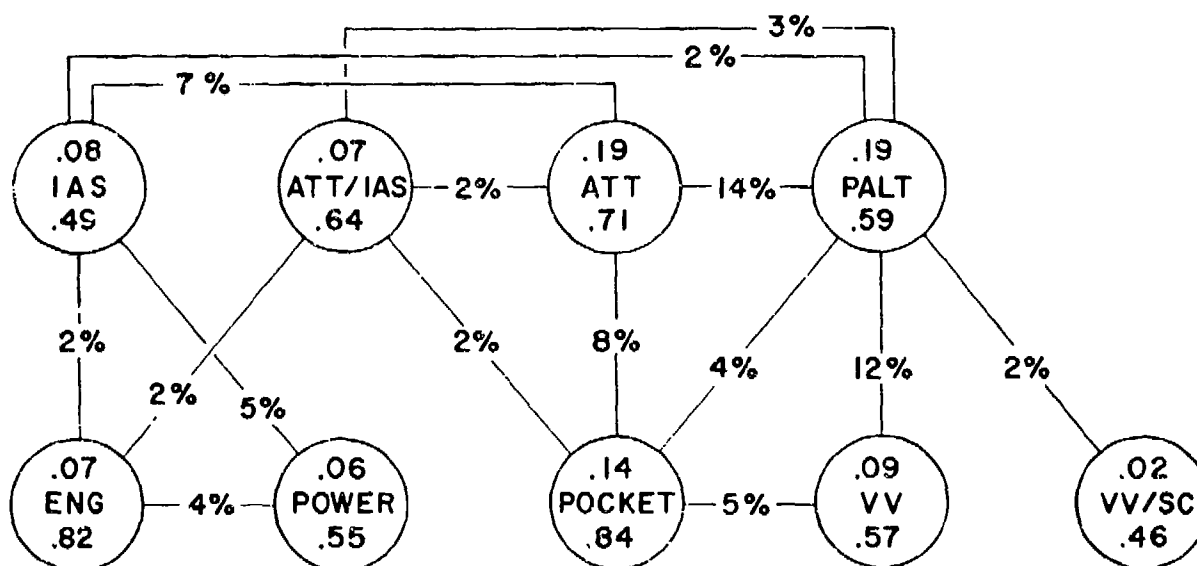
Figure 7 shows the information which was obtained from 40 Air Force pilots for ILAS (10) and GCA (3) approaches flown during daytime. Figure 8 shows the scanning behavior differences between day and night ILAS approaches flown by 15 Air Force pilots in a C-45 (12). Figure 9 provides the same information for the GCA (13) approaches. Figure 10 presents the scanning behavior of four airline pilots who performed ILS approaches using the manual ILS and the Flight-Director directed ILS in a DC-8 simulator (16). Figure 11 indicates the information obtained from 10 Air Force pilots (14) flying a T-33 jet powered aircraft using a Zero Reader instrument to monitor and direct their ILAS approach. There has been no attempt in this paper to make a statistical comparison of these different scanning behavior patterns; in most cases, the original documents have these statistical treatments for the equipment that was used and the times compared. Any attempt to compare statistically one study with another would, at best, produce doubtful results.

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
DESCENDING CONSTANT HEADING USAF TR - 5975



LINK VALUES BASED ON 36 PILOTS

ROTARYWING STEEP APPROACH



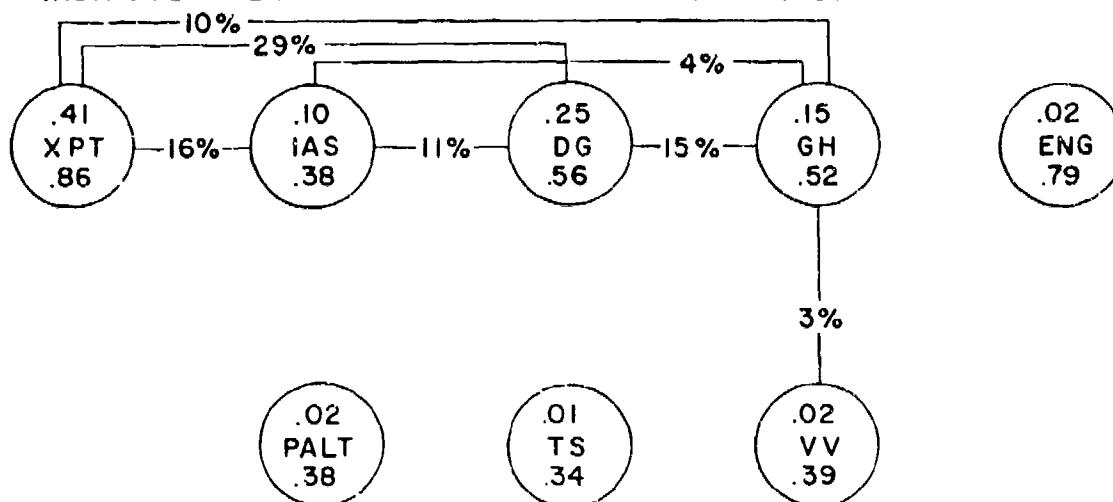
LINK VALUES BASED ON 2 FLIGHTS

VALUES LESS THAN 2% OMITTED

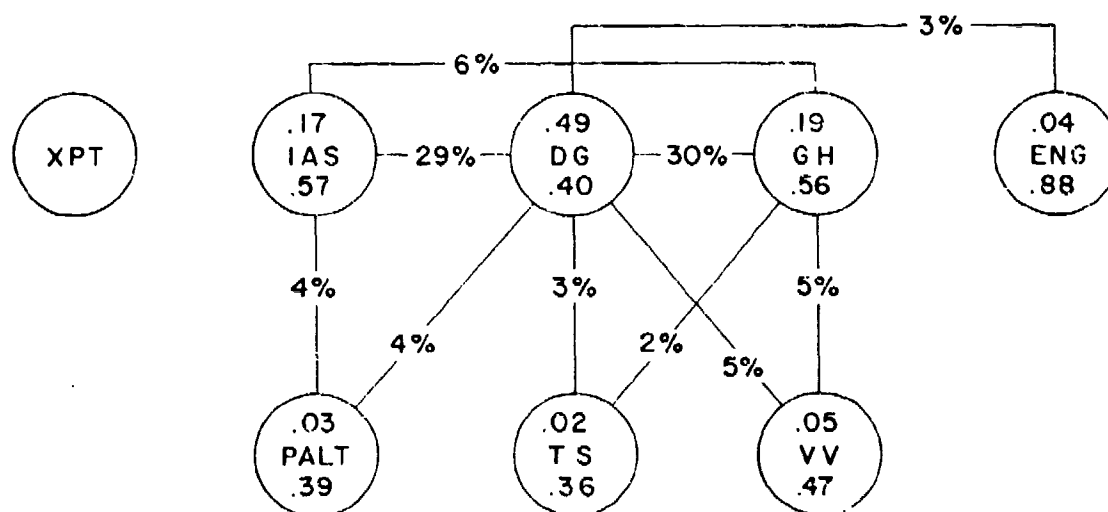
Fig 6. LINK VALUES FOR C-45 AND UH-1B
DURING A DESCENT MANEUVER

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

INSTRUMENT LANDING APPROACH SYSTEM (ILAS) USAF TR - 5839



GROUND CONTROL APPROACH (GCA) USAF TR - 6709



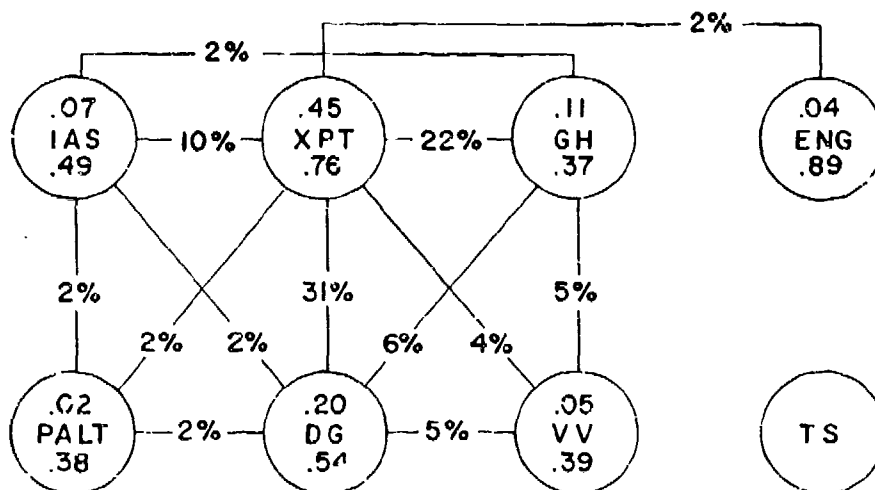
LINK VALUES BASED ON 40 PILOTS

VALUES LESS THAN 2% OMITTED

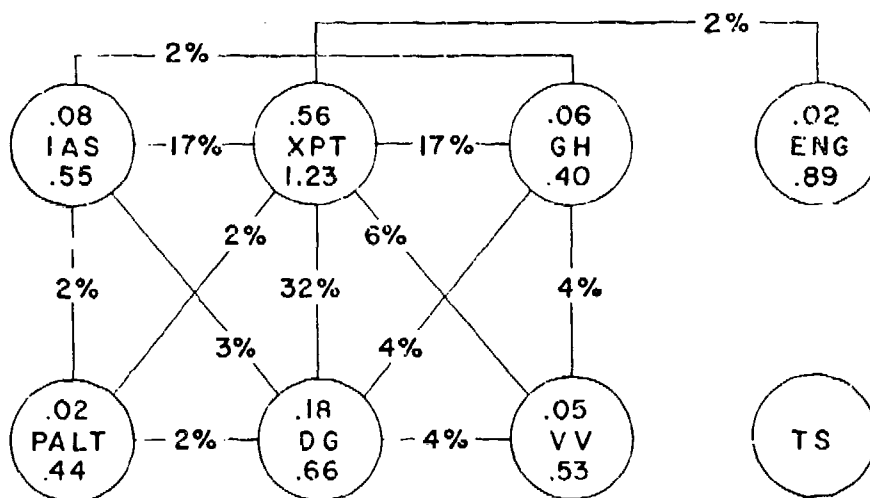
Fig 7. C-45 ILAS AND GCA APPROACHES

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

DAY ILAS USAF TR - 6570



NIGHT ILAS USAF TR - 6570



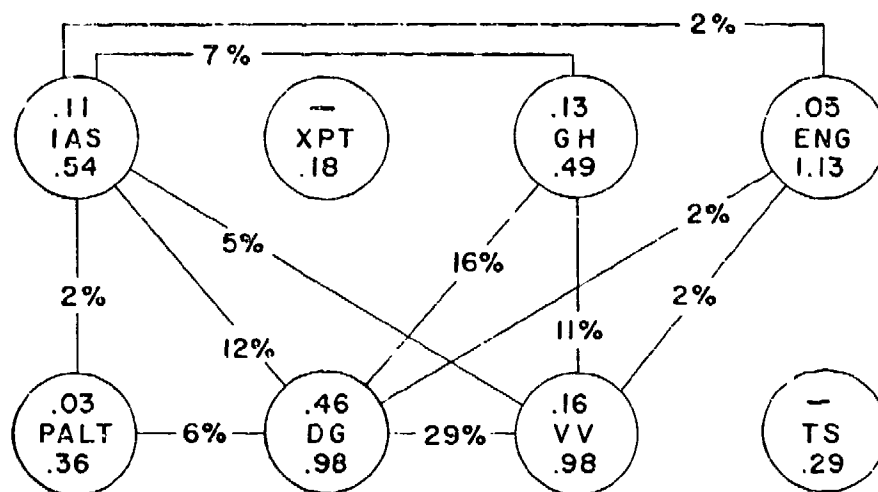
LINK VALUES BASED ON 15 PILOTS

VALUES LESS THAN 2% OMITTED

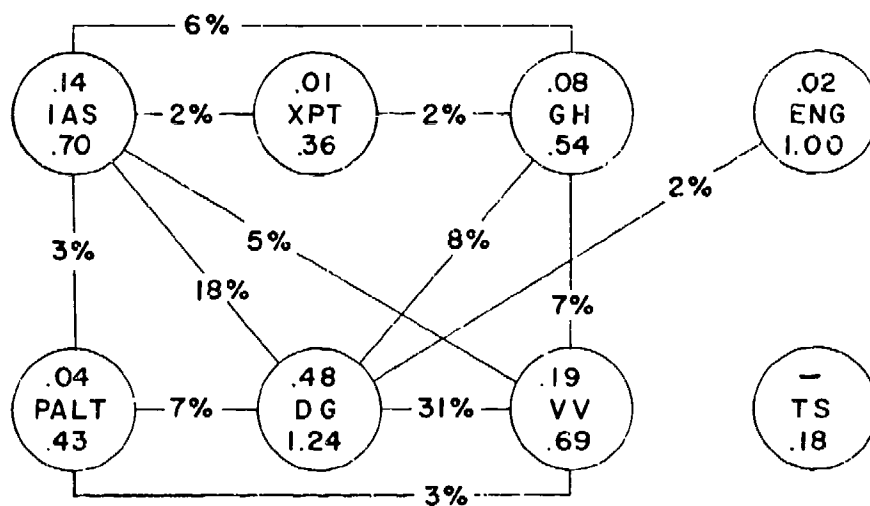
Fig 8. EXPERIMENTAL INSTRUMENT PANEL, C-45, ILAS APPROACHES

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

DAY GCA USAF TR - 6709



NIGHT GCA USAF TR - 6709



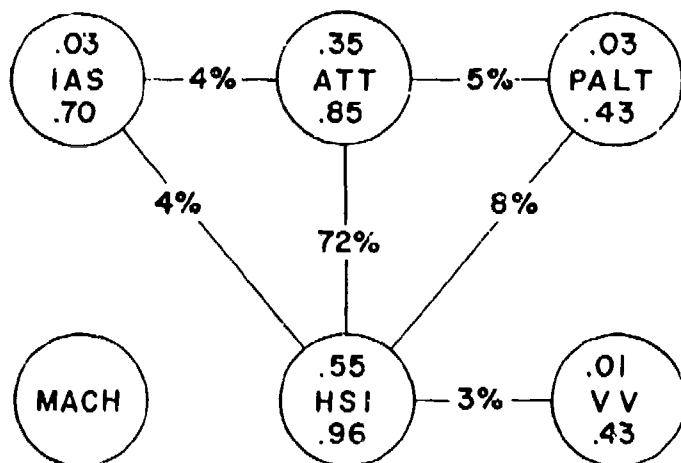
LINK VALUES BASED ON 15 PILOTS

VALUES LESS THAN 2% OMITTED

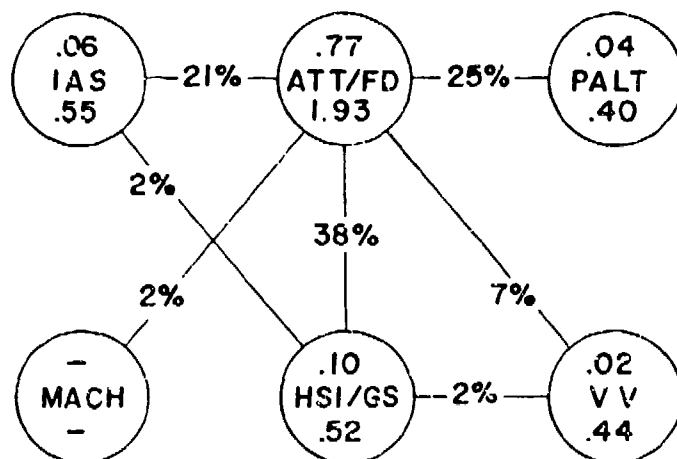
Fig 9. EXPERIMENTAL INSTRUMENT PANEL, C-45, GCA APPROACHES

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

MANUAL INSTRUMENT LANDING SYSTEM APPROACH



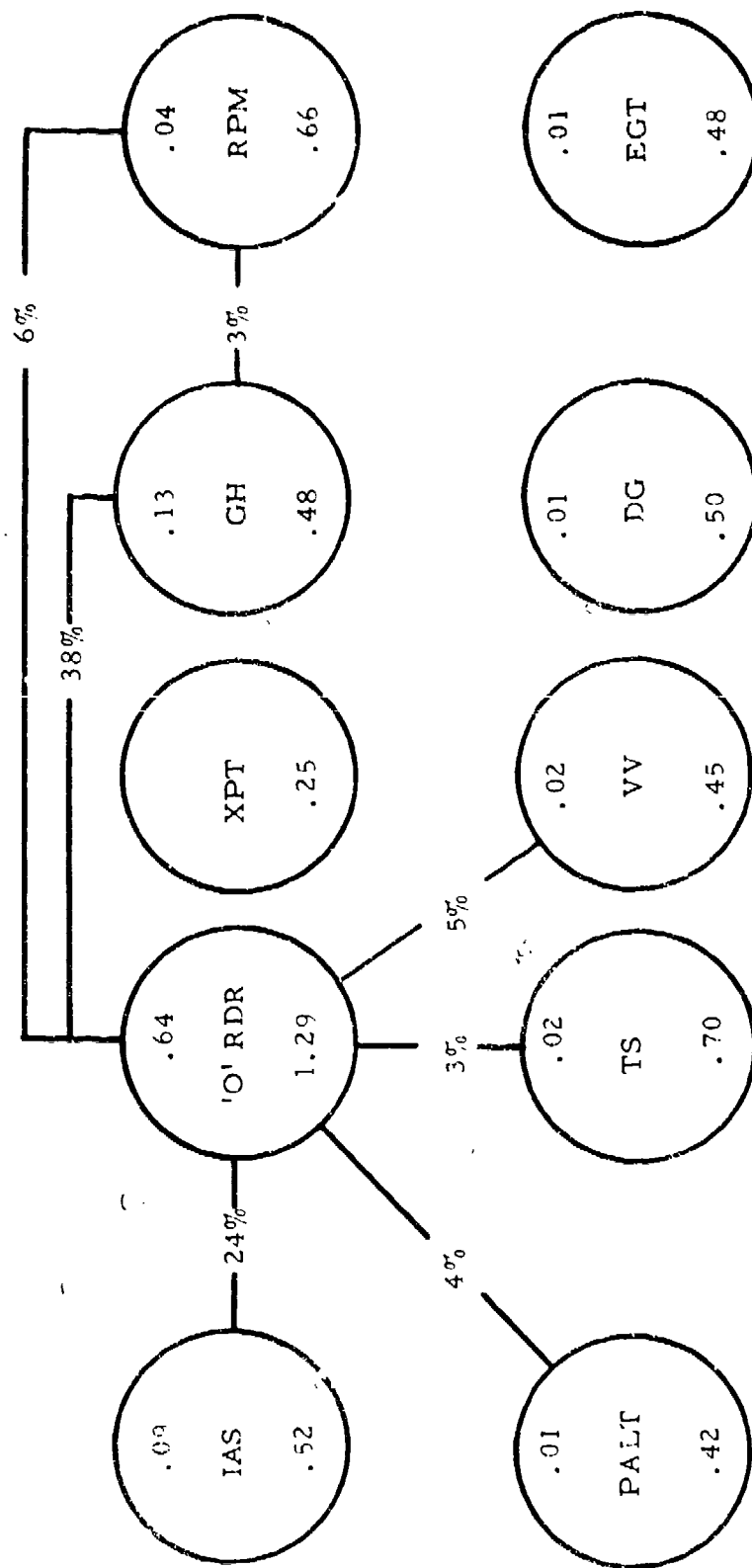
FLIGHT DIRECTOR I.L.S. APPROACH



LINK VALUES BASED ON 4 PILOTS VALUES LESS THAN 2% OMITTED

Fig 10. DC-8 ILS APPROACHES

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
ZERO READER APPROACHES USAF TR-52-17



LINK VALUES BASED ON 10 PILOTS

VALUES LESS THAN 2% OMITTED

Fig. 11. U. S. AIR FORCE T-33 ZERO READER APPROACHES

The Standard Rate/Timed Turn (Tables 31 to 33) was the next maneuver to be considered. Data on this maneuver were reported by five studies using a C-45, a UH-1B and a F-102 simulator. The C-45 (2, 7, 11) studies explored different groups of pilots and the difference between day and night performance with the same group of pilots. The F-102 (5) study looked at left versus right turns and the UH-1B (1) study looked at helicopter turns. It appears that the attitude indicator in the newer aircraft has usurped the rate of turn and slip indicator; where the dwell fractions for these two instruments were combined for the fixed-wing aircraft, their range was .29 to .40 with a mean of .35. The scan patterns obtained from these studies are shown in Figures 12, 13, 14, and 15. Straight and level or level cruise segments (Tables 33 and 34) are reported parts of four studies concerning the same aircraft as the Standard Rate Turn (Tables 31 and 32). The helicopter pilots appeared to pay less attention to their direction control than did the fixed-wing pilots but the remainder of their scanning behavior was quite similar. The link values and scanning patterns are shown in Figures 16 and 17 for the C-45 and UH-1B; the F-102 pattern was not given in the original study.

The climb maneuver with and without a turn was a reported maneuver in four studies concerned with the same three aircraft as in the previous maneuvers. There was little difference between the pilots' dwell fraction values (Table 35) if the helicopter "pocket" value is distributed among the four instruments that make up this fixation point. The helicopter pilots did appear to attend to altitude more than the fixed-wing pilots. The "Td" values given in Table 36 showed the same situation, especially in the helicopter pilots' use of the altimeter. The link values and scanning patterns for these maneuvers are given in Figures 18, 19 and 20. The last maneuver to be considered was the descending turn, which was reported by two studies. The "n" and "Td" values shown in Tables 37 and 38 indicate the same differences in technique as in prior maneuvers, but the UH-1B sample is too small to allow any valid conclusions to be made.

Table 39 shows the amount of time pilots spent looking inside and outside of the cockpit during visual landings; additional dwell fraction times are shown for time spent on instruments when the pilot was looking inside the cockpit. The inside/outside ratio of 1:3 for landing appears to be constant across this rather diverse group of aircraft which includes a helicopter and a Navy fighter, as well as light, medium and heavy transports. These aircraft were powered by turbine and piston engines driving propellers or rotor blades, and by pure jet propulsion. The take-off data shown in Table 40 were essentially the same for the transport aircraft with a 3:2 inside/outside ratio, but the helicopter data showed a 4:1 ratio. This difference may have been a result of the helicopter not depending on forward velocity for lift, which would allow the pilot to spend a greater proportion of his time looking inside the cockpit. This difference was emphasized when the dwell fraction times for instruments was considered. The helicopter pilots used 69 percent of the time that they were looking inside the cockpit (80 percent of the total time) on the Attitude Indicator, Altimeter, Vertical Velocity and Airspeed, while the C-45 (light transport) pilots used 19 percent of the inside time on these instruments.

TABLE 31

Standard Rate Turn -- Dwell Fraction "n"

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	HSI	DG	ENG	TS	INST	PWR	POCKET
M-1 (PBY-5A)													
MJF-2 (C-45)													
JMF-4 (C-45)		.29	.12	.06	.12	--	.26	.06	.04				
MJF-5 (C-45) TIMED		.20	.06	.02	.02	--	.30	.18	--	.16*			
CMM-9 (C-45) TIMED		.25	.15	.11	.05	.01	.22	.04	.02	.01*			
CMM-9 (C-45) DAY		.29	.18	.14	.07	.01	.16	.07	.03				
CMM-9 (C-45) NIGHT		.30	.21	.13	.11	.01	.14	.08	.02				
MW-8 (T-33)													
B-1 (UH-1B)		.16	.16	.04	.05	--	.08	--	.06	.04	.13		
GO-1 (F-102 Simulator) RIGHT		.40	.04	.10	.01	.04	.10						
GO-1 (F-102 Simulator) LEFT		.39	.05	.16	.01	.02	.14						
WK-1 (DC-8 Simulator)													
SCW-1 (C-11B Simulator)		.41	.19	.08	.09	--	.22						
Clock													

TABLE 32

Standard Rate Turn -- Mean Dwell Time " $\overline{T_d}$ "

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	HSI	DG	RMI	TS	INST	PWR	PKT
M-1 (PBX-5A)													
MJF-2 (C-45)													
FJM-3 (C-45)													
IMF-4 (C-45)		.70	.50	.39	.52	--		.60	.44	.93			
MJF-5 (C-45) TIMED		.82	.47	.58	.52	--		1.03	.85	--	.80*		
CMM-9 (C-45) TIMED		.67	.42	.36	.45	.25		.51	.60	.75	.60*		
CMM-9 (C-45) DAY		.73	.44	.38	.49	.27		.47	.61	.85			
CMM-9 (C-45) NIGHT		.86	.63	.52	.64	.26		.64	.79	.94			
B-1 (UH-1B)		.58	.62	.62	.62	--		1.07	--	.67	.54	.75	
GO-1 (F-102 Simulator) RIGHT		.46	.35	.36	.23	.31		.45					
GO-1 (F-102 Simulator) LEFT		.44	.42	.51	.35	.26		.63					
WK-1 (DC-8 Simulator)													
*Clock													

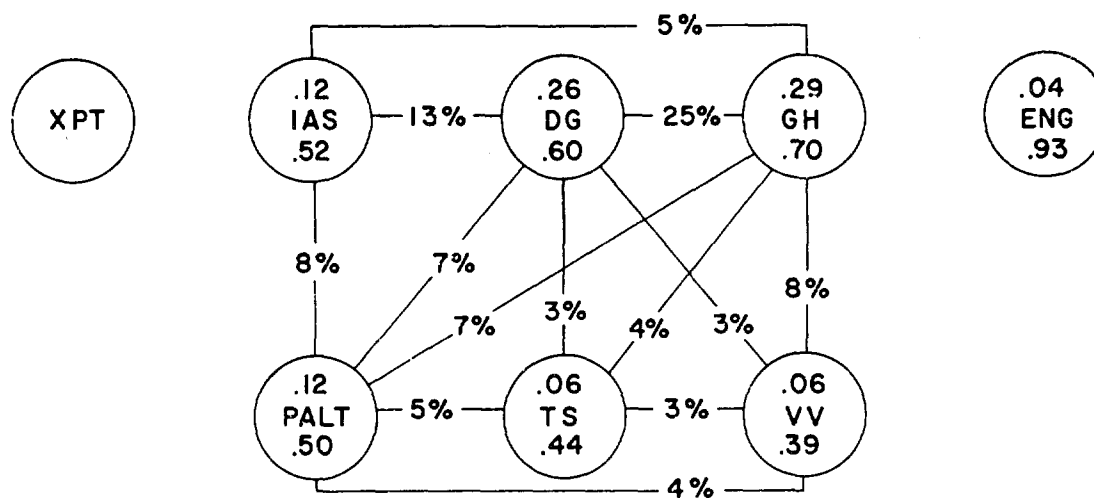
TABLE 33

Level Cruise -- Dwell Fraction "n"

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	RMI	TS	DG	ENG	INST	PWR	PKT
M-1 (PBY-5A)													
MJF-2 (C-45)													
FJM-3 (C-45)													
JMF-4 (C-45)													
MJF-5 (C-45)		.25	.13	.05	.07	--	.37	.03	.02				
CMM-9 (C-45) DAY		.14	.19	.12	.12	.02	.30	.01	.05				
CMM-9 (C-45) NIGHT		.18	.20	.12	.14	.03	.29	.01	.01				
MW-8 (T-33)													
B-1 (UH-1B)		.12	.14	.03	.07	--	.04	.01	.07	.12			
GO-1 (F-102 Simulator)		.26	.05	.17	.01	.04	.18						
WK-1 (DC-8 Simulator)													

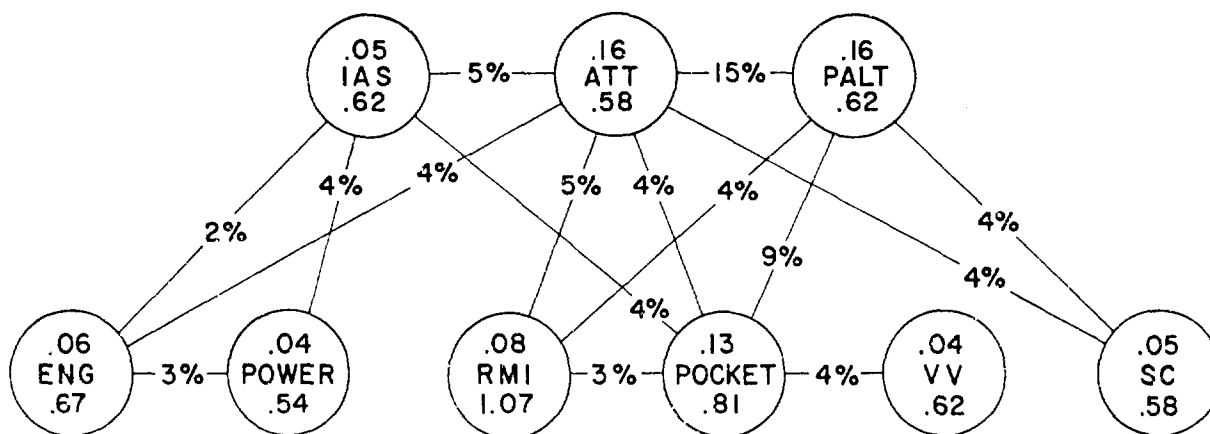
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

LEVEL TURN USAF TR- 5975



LINK VALUES BASED ON 36 PILOTS

ROTARY WING STANDARD RATE TURN



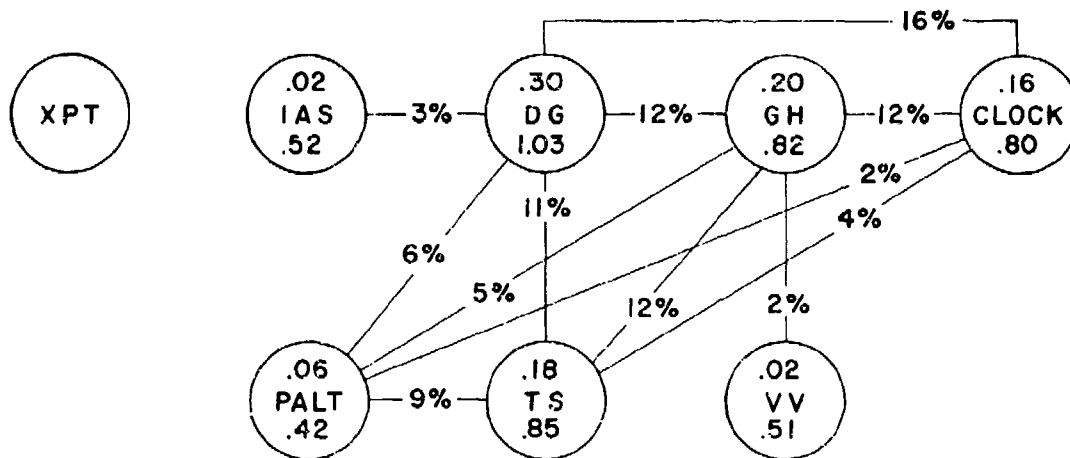
LINK VALUES BASED ON 3 FLIGHTS

VALUES LESS THAN 2% OMITTED

Fig 12. COMPAIRISON OF UH-1B AND C-45 LINK VALUES

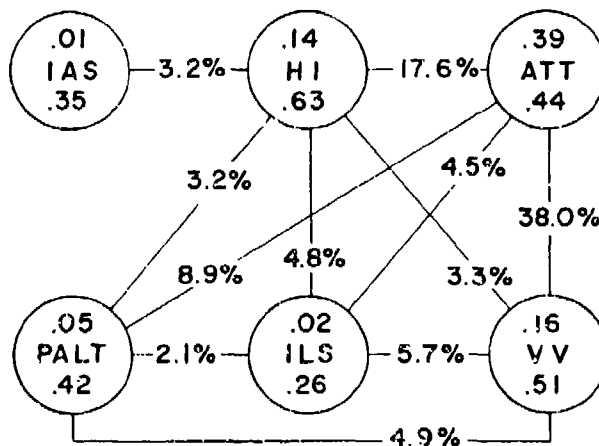
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

STANDARD RATE (TIMED) TURN USAF TR-6018



LINK VALUES BASED ON 9 PILOTS

STANDARD RATE (LEFT) TURN GAINER, OBERMEYER

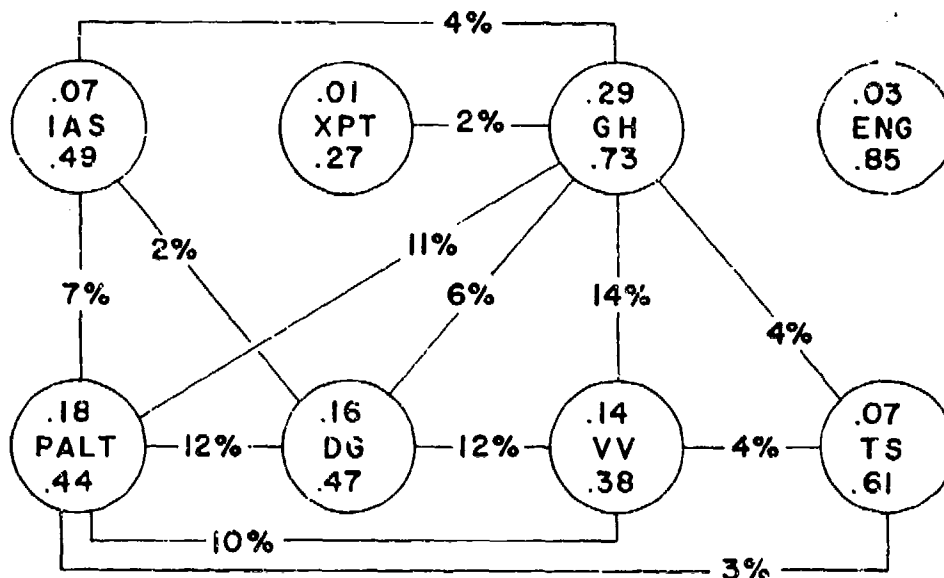


LINK VALUES BASED ON 16 PILOTS VALUES LESS THAN 2% OMITTED

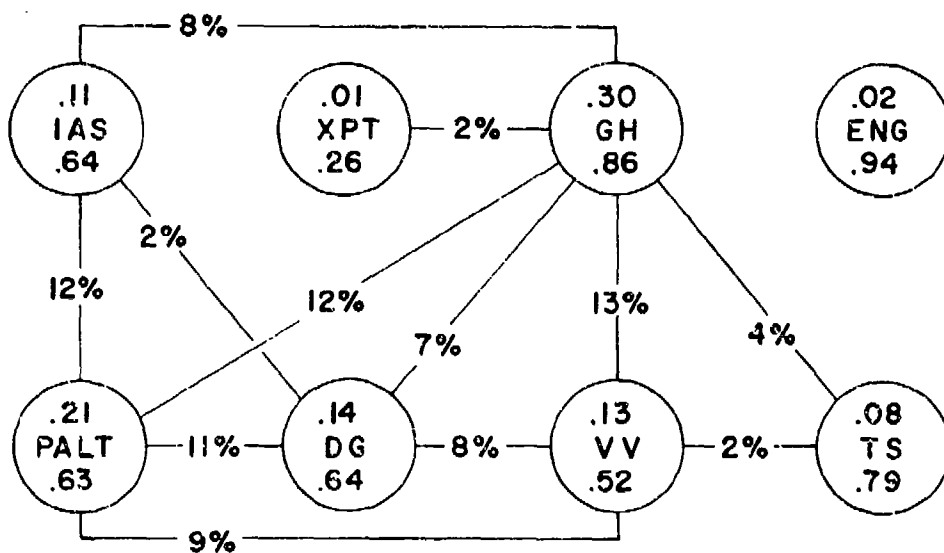
Fig 13. COMPARISON OF F-102 AND C-45 LINK VALUES

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

DAY LEVEL TURN



NIGHT LEVEL TURN

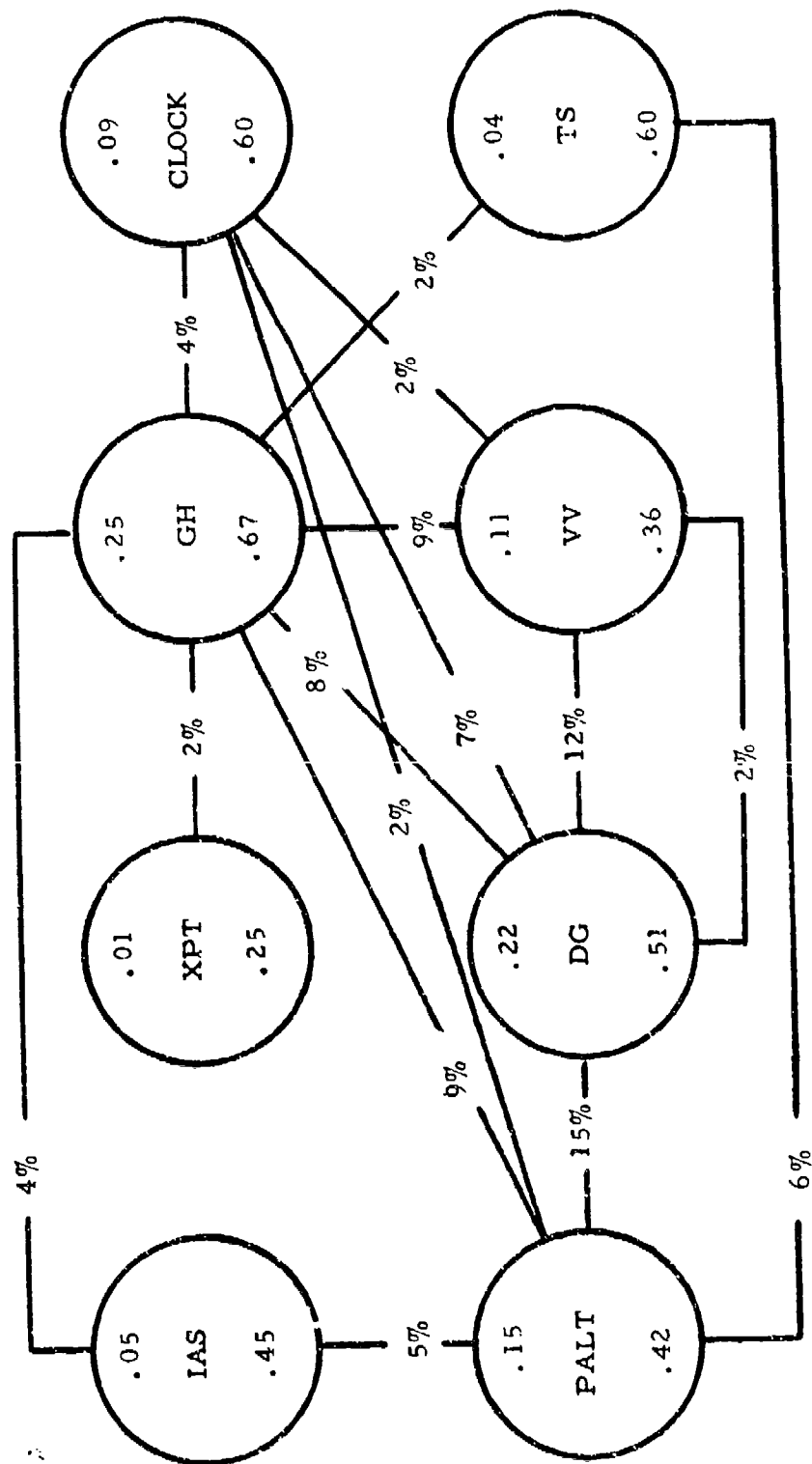


LINK VALUES BASED ON 15 PILOTS

VALUES LESS THAN 2% OMITTED

Fig 14. C-45 LINK VALUES FROM WADC TR-53 - 220

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
DAY 180° TIMED TURN WADC TR-53-220



LINK VALUES BASED ON 15 PILOTS

VALUES LESS THAN 2% OMITTED

Fig. 15. U. S. AIR FORCE C-45 DAY 180-DEGREE TIMED TURN

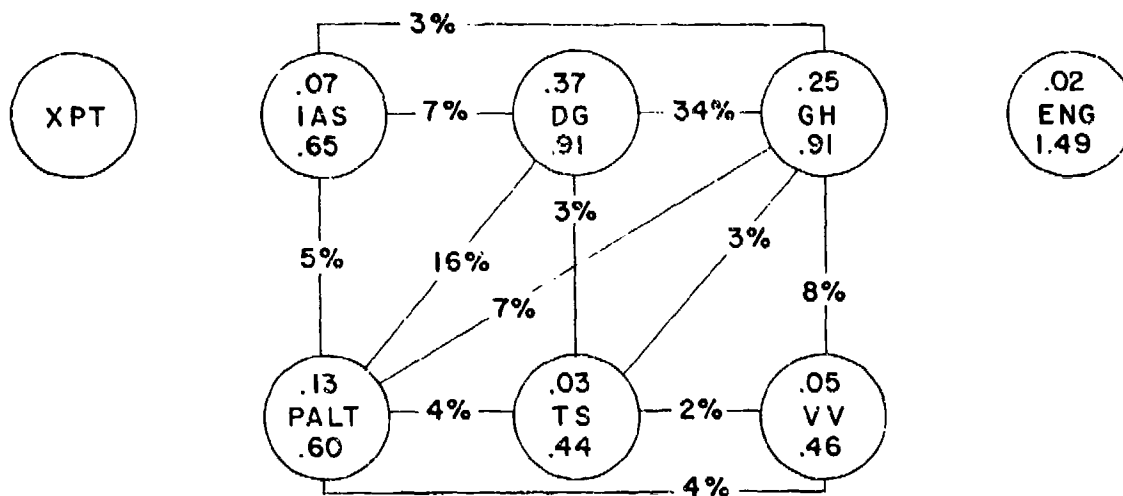
TABLE 34

Level Cruise -- Mean Dwell Time " $\overline{T_d}$ "

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	RMI	TS	INST	PWR	PKT
M-1 (PBY-5A)											
MJF-2 (C-45)											
FJM-3 (C-45)											
JMF-4 (C-45)											
MJF-5 (C-45)		.91	.60	.46	.65	---	.91	.44	1.49		
CMM-9 (C-45) DAY		.50	.46	.39	.54	.25	.66	.46	.96		
CMM-9 (C-45) NIGHT		.58	.56	.45	.70	.33	.82	.54	.76		
MW-8 (T-33)											
B-1 (UH-1B)		.59	.57	.43	.46	---	.62	.58	.87	.61	.82
GO-1 (F-102 Simulator)		.43	.39	.54	.29	.27	.56				
SCW-1 (C-11B Simulator)											
WK-1 (DC-8 Simulator)											

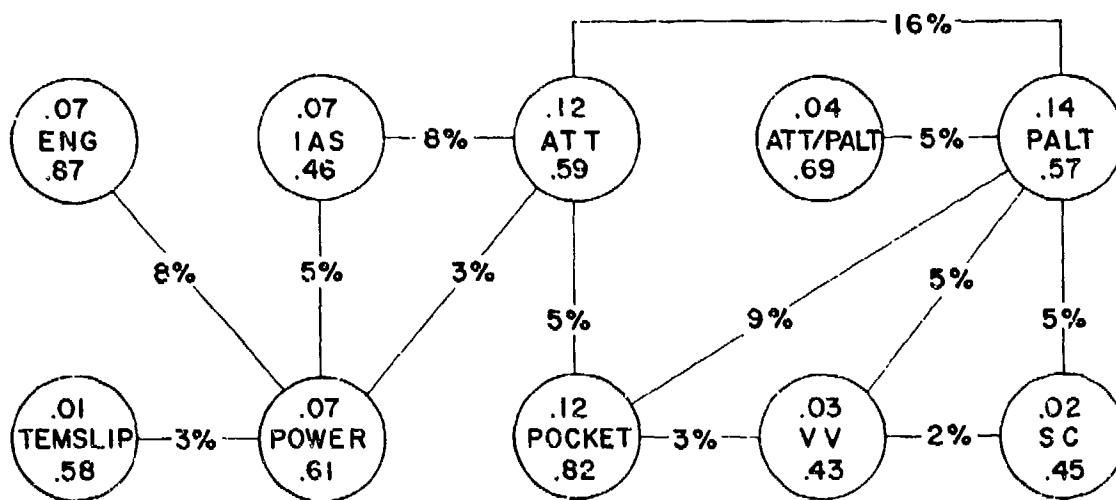
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

STRAIGHT & LEVEL USAF TR-6018



LINK VALUES BASED ON 10 PILOTS

ROTARYWING STRAIGHT & LEVEL



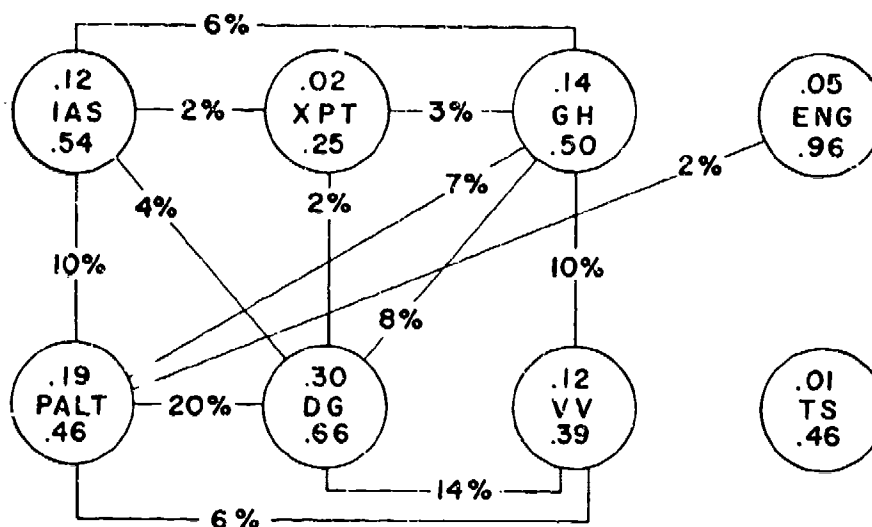
LINK VALUES BASED ON 4 FLIGHTS

VALUES LESS THAN 2% OMITTED

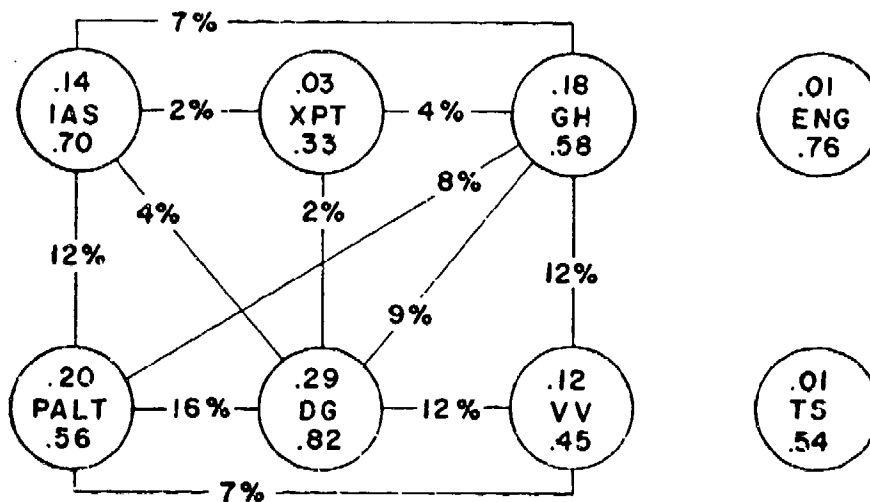
Fig 16. COMPARISON OF UH-1B AND C-45 LINK VALUES

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

DAY STRAIGHT AND LEVEL



NIGHT STRAIGHT AND LEVEL



LINK VALUES BASED ON 15 PILOTS VALUES LESS THAN 2% OMITTED

Fig 17. C-45 LINK VALUES FROM WADC TR-53-220

TABLE 35

Climb -- Dwell Fraction "n"

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	HSI	DG	RMI	TS	INST	PWR	PKT	ENG
M-1 (PBY-5A)														
MJF-2 (C-45)														
JMF-4 (C-45)		.24	.07	.09	.24	--		.20	.03	.10				
JMF-4 (C-45) w/TURN		.28	.07	.08	.16	--		.23	.05	.09				
MJF-5 (C-45)														
MMC-6 (C-45) w/TURN														
CMM-9 (C-45) w/TURN		.24	.08	.28	.13	.01		.16	.01	.06				
B-1 (UH-1B)		.10	.14	.09	.10	--		.03	.02	.04	.05	.10		
B-1 (UH-1B) w/TURN		.17	.16	.04	.05	--		.04	.02	.05	.08	.17		
GO-1 (F-102 Simulator)		.24	.03	.06	.11	.03		.20						
SCW-1 (C-11 B Simulator)														
WK-1 (DC-8 Simulator)														

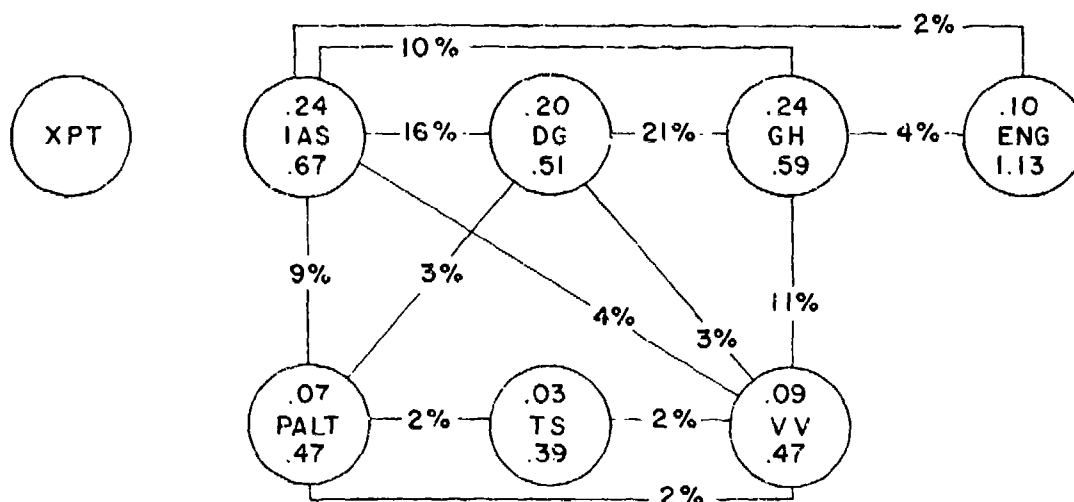
TABLE 36

Climb -- Mean Dwell Time " $\overline{T_d}$ "

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	HSI	DG	RMI	TS	INST	PWR	PKT	ENG
M-1 (PBY-5A)														
MJF-2 (C-45)														
JMF-4 (C-45)		.59	.47	.47	.67	--	.51	.39	1.13					
JMF-4 (C-45) w/TURN		.70	.44	.48	.58	--	.56	.48	1.11					
MJF-5 (C-45)														
MMC-6 (C-45)														
CMM-9 (C-45) w/TURN		.63	.42	.61	.53	.21	.54	.49	.99					
B-1 (UH-1B)		.57	.58	.65	.47	--	.53	.39	.95	.81	.76			
B-1 (UH-1B) w/TURN		.83	.90	.53	.53	--	1.00	1.00	.90	.70	1.17			
GO-1 (F-102 Simulator)		.39	.43	.43	.48	.32	.54							
SCW-1 (C-11 B Simulator)														
WK-1 (DC-8 Simulator)														

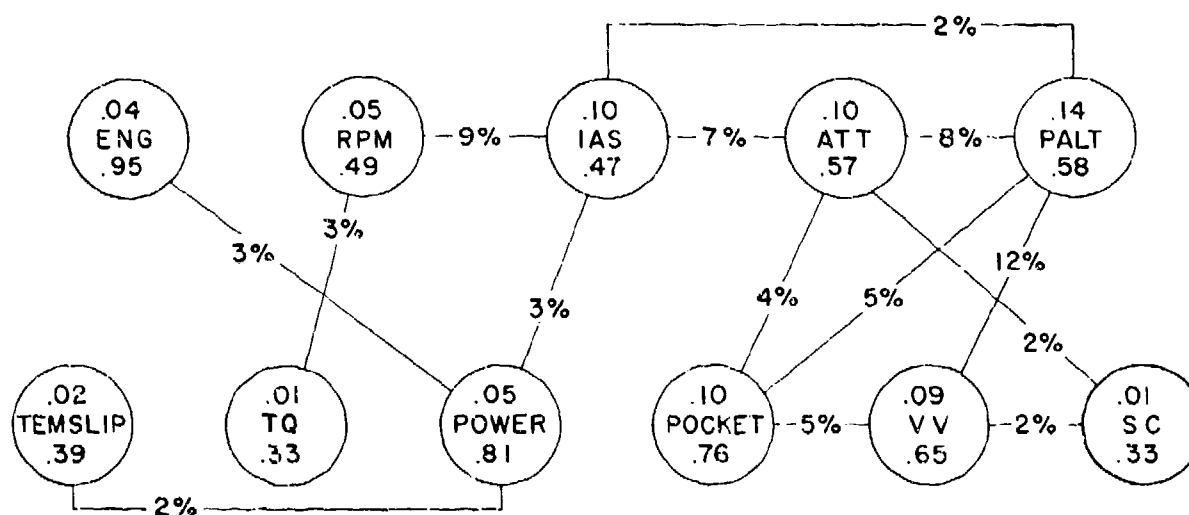
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

CLIMBING (CONSTANT HEADING) USAF TR-5975



LINK VALUES BASED ON 36 PILOTS

ROTARY WING IFR CLIMB



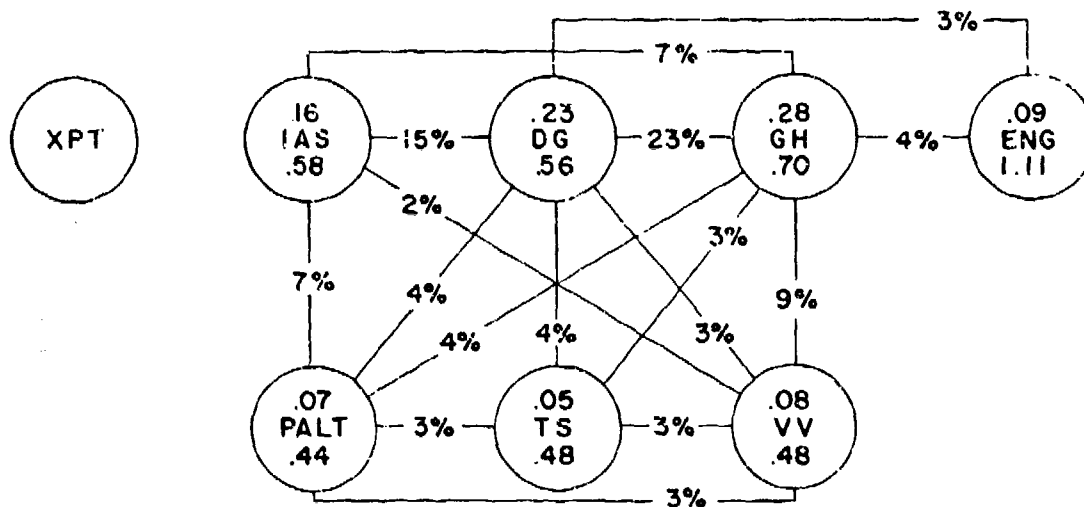
LINK VALUES BASED ON 2 FLIGHTS

VALUES LESS THAN 2% OMITTED

Fig 18. COMPARISON OF UH-1B AND C-45 LINK VALUES

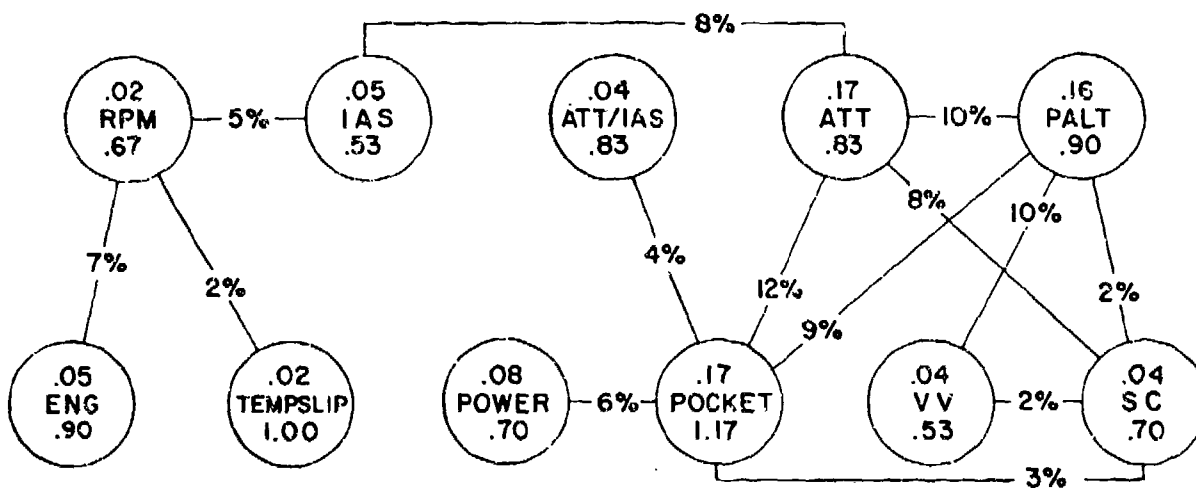
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

CLIMBING TURN USAF TR- 5975



LINK VALUES BASED ON 36 PILOTS

ROTARY WING CLIMBING TURN



LINK VALUES BASED ON 1 FLIGHT

VALUES LESS THAN 2% OMITTED

Fig 19. COMPAIRISON OF UH-1B AND C-45 LINK VALUES

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
DAY CLIMBING TURN WADC TR-53-220

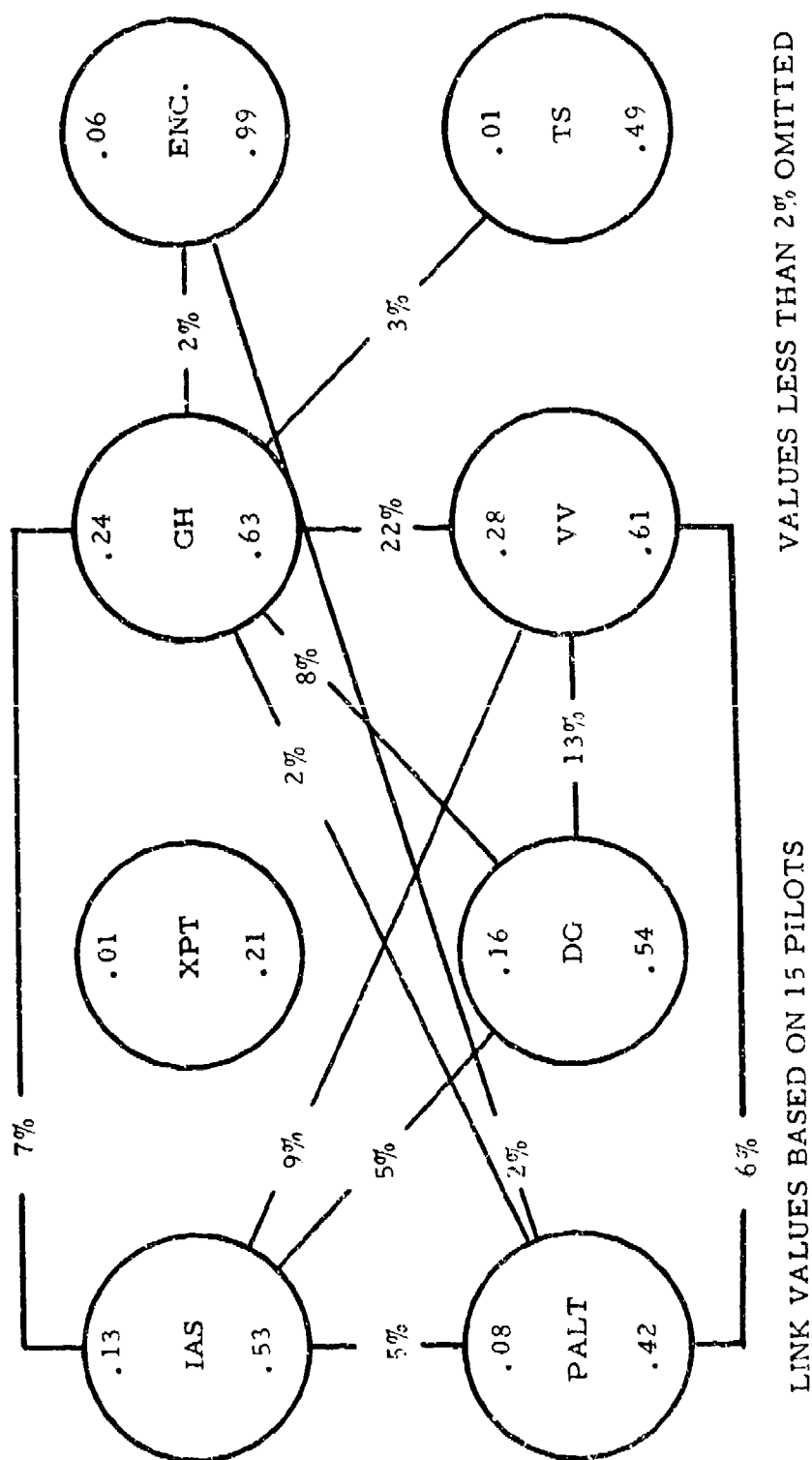


Fig. 20. U. S. AIR FORCE C-45 DAY CLIMBING TURN

TABLE 37

Descending Turn -- Dwell Fraction "n"

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	HSI	DG	TS	INST	PWR	PKT
M-1 (PBX-5A)												
MJF-2 (C-45)												
FJM-3 (C-45)												
JMF-4 (C-45)		.25	.06	.07	.19	--	.24	.05	.10			
MJF-5 (C-45)												
MMC-6 (C-45)												
MMC-7 (C-45)												
MW-8 (T-33)												
B-1 (UH-1B)		.30	.15	.10	.08	--	.01	.03	.02	.03	.12	
GO-1 (F-102 Simulator)												
SCW-1 (C-11 D Simulator)												
WK-1 (DC-8 Simulator)												

TABLE 38

Descending Turn -- Mean Dwell Time " $\overline{T_d}$ "

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	HSI	DG	TS	ENG	INST	PWR	PKT
M-1 (PBY-5A)													
MJF-2 (C-45)													
FJM-3 (C-45)													
JMF-4 (C-45)		.63	.45	.45	.61	--	.59	.46	1.13				
MJF-5 (C-45)													
MMG-6 (C-45)													
MMG-7 (C-45)													
MW-8 (T-33)													
B-1 (UH-1B)		.84	.72	.72	.55	--	.33	1.50	.53	.60	1.11		
GO-1 (F-102 Simulator)													
SCW-1 (C-11 B Simulator)													
WK-1 (DC-8 Simulator)													

TABLE 39

VFR Landing -- Dwell Fraction "n"

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	RMI	ENG	OUT	IN	NO
								INST	A/C	A/C	S'S
L-1 (Electra L-188)								.71	.25	.26	
L-1 (Boeing 707)								.79	.18	.9	
G-1 (A-4 Simulator)								.73	.27	.28	
FJM-3 (C-45)											
MJF-4 (C-45)											
MJF-5 (C-45)		--	.06	--	.17	--	.04	--	.73	.27	.9
MMC-6 (C-45)											
MMC-7 (C-45)											
MW-8 (T-33)											
B-1 (UH-1B)*		.04	.05	.01	.04	--	.03	.07	.75	.25	.2
GO-1 (F-102 Simulator)											
SCW-1 (C-11 B Simulator)											
WK-1 (DC-8 Simulator)											
*Data from Table A2											

"VERTICAL DESCENT"

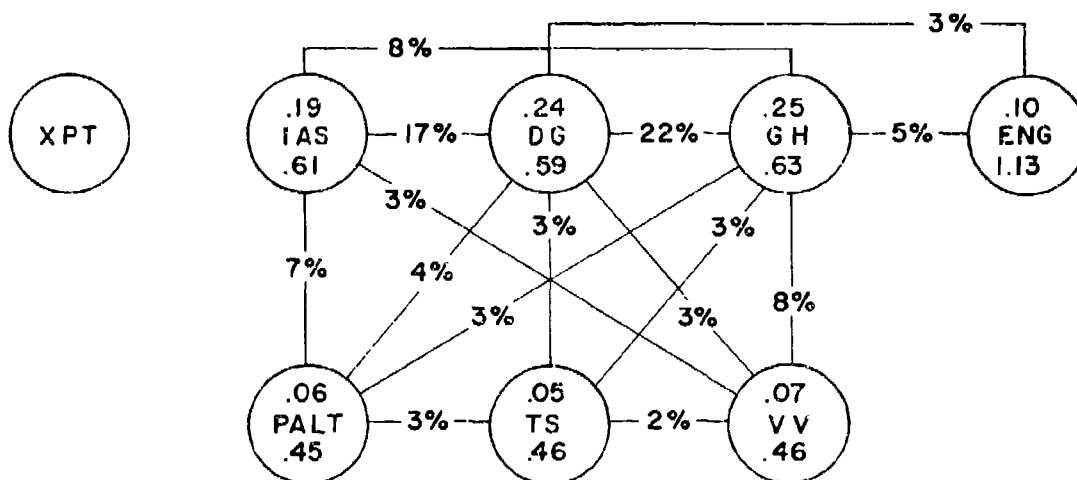
TABLE 40

VFR Takeoff -- Dwell Fraction "n"

INSTRUMENT	STUDY	ATT	PALT	VV	IAS	XPT	HSI	DG	ENG	OUT	IN	NO
										A/C	A/C	S'S
L-1 (Electra L-188)										.36*	.60*	26
L-1 (Boeing 707)										.38	.59	9
MJF-2 (C-45)												
FJM-3 (C-45)												
MJF-5 (C-45) 1st Half		.01	--	.01	.04	--	.02	.11	.81	.19	10	
MJF-5 (C-45) 2nd Half		.02	.01	.07	.09	--	.02	.42	.37	.63	9	
MMC-6 (C-45)												
MMC-7 (C-45)												
MW-8 (T-33)												
B-1 (UH-1B)		.23	.23	.16	.07	--	.06	.10*	.22*	.78*	2	
GO-1 (F-102 Simulator)												
SCW-1 (C-11 B Simulator)												
WK-1 (DC-8 Simulator)												
*VFR, STEEP CLIMB FROM HOVER												

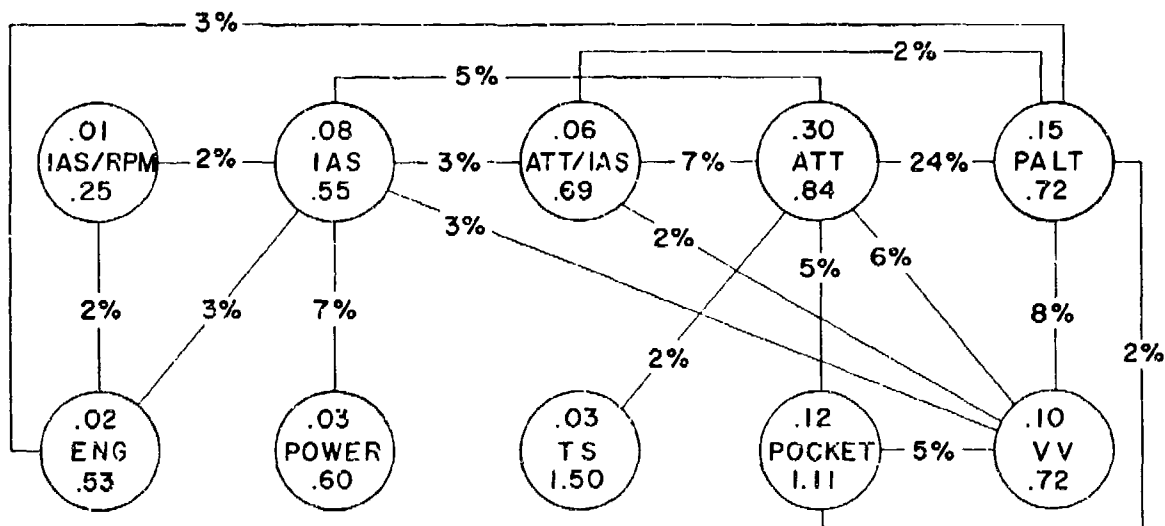
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

DESCENDING TURN USAF TR-5975



LINK VALUES BASED ON 36 PILOTS

ROTARYWING DESCENDING TURN

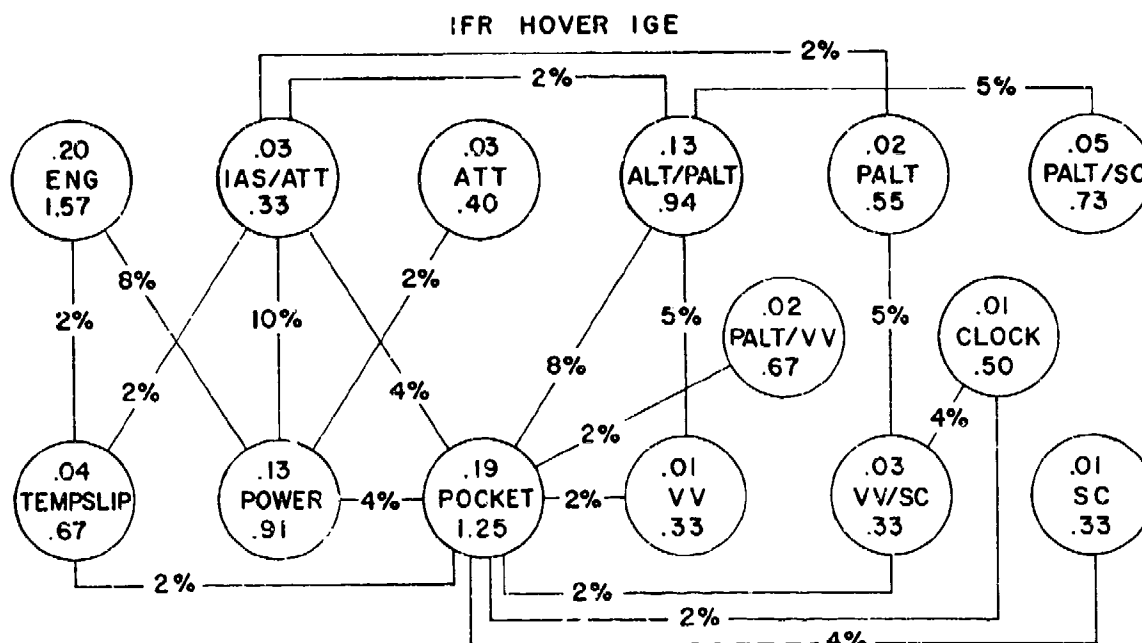


LINK VALUES BASED ON 1 FLIGHT

VALUES LESS THAN 2% OMITTED

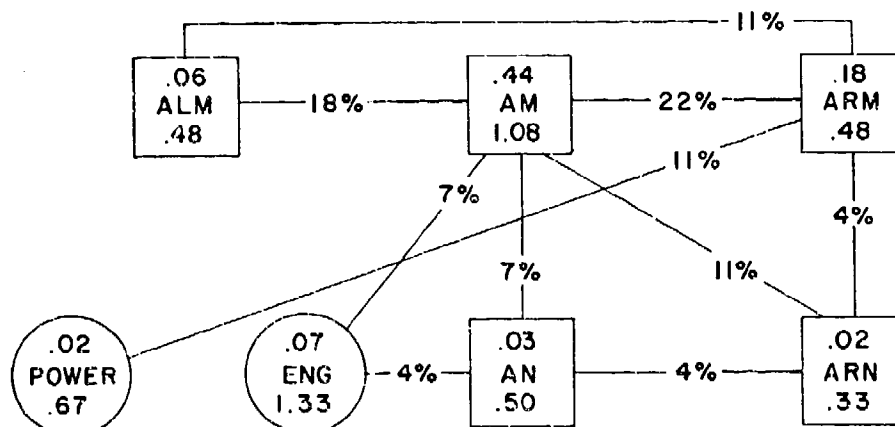
Fig 21. COMPARISON OF UH-1B AND C-45 LINK VALUES

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS



LINK VALUES BASED ON 1 FLIGHT

VFR HOVER IGE



LINK VALUES BASED ON 1 FLIGHT

VALUES LESS THAN 2% OMITTED

Fig 22. UH-1B LINK VALUES

IFR HOVER OGE 500'

2%

8%

.04
ENG
.67

.07
IAS
.47

—
ATT/IAS
.33

.23
ATT
.68

.20
PALT
.57

26%

3%

10%

.04
TEMP/SLIP
.89

.13
POWER
.58

.15
POCKET
.83

.05
VV
.41

6%

10%

2%

8%

9%

6%

3%

LINK VALUES BASED ON 1 FLIGHT

Figure 1 is a path diagram illustrating the hypothesized relationships between 12 variables. The variables are represented by rectangles (latent variables) and circles (observed variables). Standardized path coefficients are shown on the arrows, and error variances are shown inside the rectangles.

The variables and their error variances (in rectangles) are:

- AM (.44)
- RM (1.42)
- FRM (.67)
- LN (.44)
- AN (.32)
- RN (.78)
- FRN (.87)
- ENG (.37)
- RPM (.37)
- IAS (.61)
- ATT (.61)
- PALT/ATT (1.35)
- PALT (.48)
- TEMPSLIP (.12)
- POWER (.45)

The hypothesized paths and their standardized coefficients are:

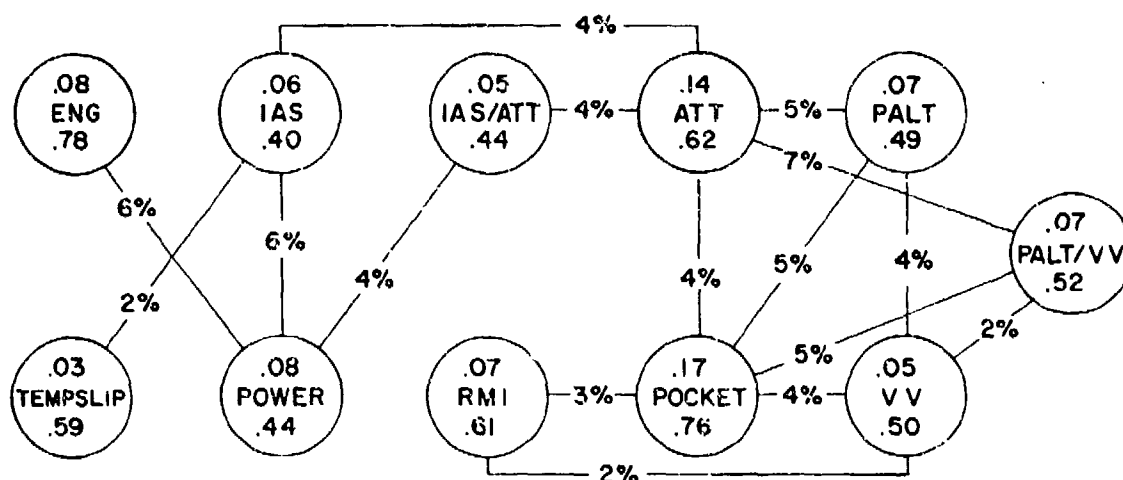
- AM to RM: 2%
- AM to FRM: 2%
- RM to FRM: 2%
- LN to AN: 2%
- AN to RN: 2%
- AN to FRN: 2%
- AN to ENG: 4%
- AN to RPM: 2%
- AN to IAS: 3%
- AN to ATT: 4%
- AN to PALT/ATT: 2%
- AN to PALT: 2%
- AN to POWER: 5%
- RN to FRN: 1%
- RN to PALT/ATT: 2%
- RN to PALT: 4%
- FRN to PALT: 2%
- PALT/ATT to PALT: 2%
- ENG to RPM: 4%
- RPM to IAS: 2%
- TEMPSLIP to IAS: 2%
- IAS to ATT: 2%
- IAS to POWER: 2%
- ATT to PALT/ATT: 2%
- ATT to PALT: 4%
- ATT to POWER: 2%

VALUES LESS THAN 2% OMITTED

64

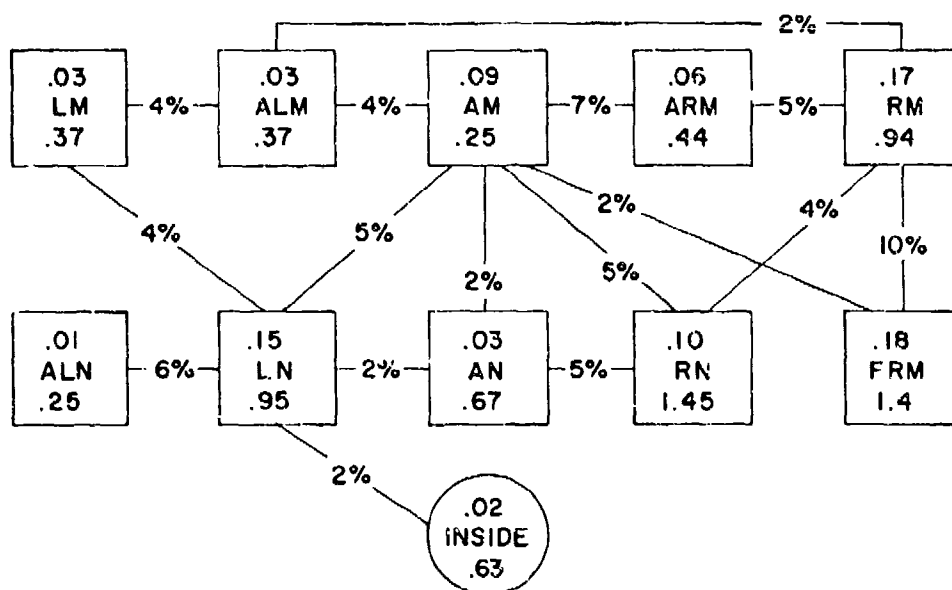
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

IFR LOW LEVEL CRUISE



LINK VALUES BASED ON 1 FLIGHT

TERRAIN FOLLOWING VFR



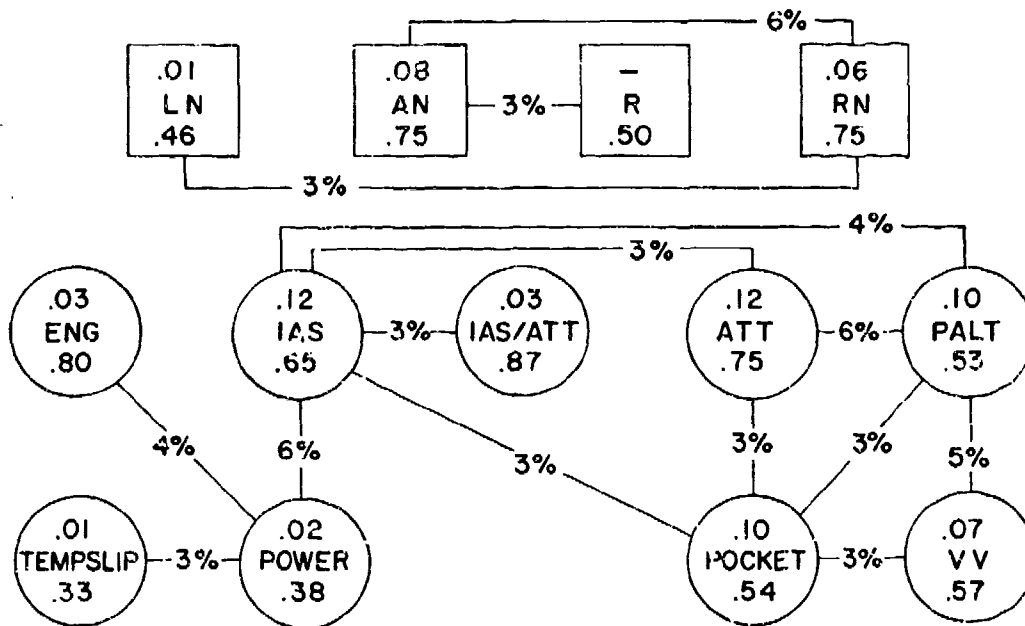
LINK VALUES BASED ON 1 FLIGHT

VALUES LESS THAN 2% OMITTED

Fig 24. UH-1B LINK VALUES

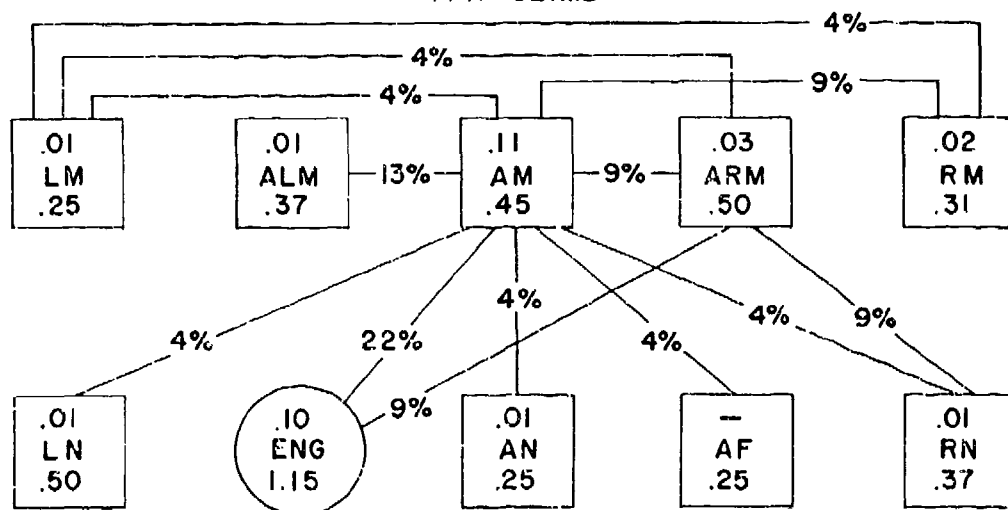
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

VERTICAL DESCENT



LINK VALUES BASED ON 2 FLIGHTS

VFR CLIMB



LINK VALUES BASED ON 1 FLIGHT

VALUES LESS THAN 2% OMITTED

Fig 25. UH-1B LINK VALUES

SUMMARY

The data in this paper represent the major portion of the aircraft eye-movement work that has been reported in the United States in the past 25 years. The aircraft reported on range from single-engine monoplanes to four-engine transports, from single-jet trainers and fighters to four-jet transports, and they also include a single-turbine medium helicopter. It provides the eye-movement data in the same format so that there should be no mistakes interpreting what a particular author was talking about when he presented a numerical measure. The mean dwell times, \bar{T}_d , and the dwell fractions, n , were in every case those reported by the original authors. The remaining data for the values of N_i , f_s and T_i were computed from the reported data. The link values used in the diagrams are those reported in the original studies and the diagrams, in a standardized form, are also taken from the original studies.

The differences in values among studies show our progress, or lack of thereof, in presenting information to the pilots. The link diagrams show the effect of panel design on scanning workload and indicate some need for instrument combination and redesign. This finding is especially true of the helicopter study which, by the reporting of fixation points between instruments, shows what information could be combined to aid the pilot and allow him more time for other tasks.

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APPENDIX A

TACTICAL UTILITY HELICOPTER INFORMATION TRANSFER STUDY¹

INTRODUCTION

The object of this effort was to analytically determine the information needs of the flight crew of a tactical utility helicopter which could be satisfied by basic flight instrumentation. Three typical utility helicopter missions were considered in the study:

1. Utility Transport Mission
2. Rescue Mission
3. Fire Support Mission

These missions were broken into segments or tasks, such as Hover in Ground Effect, and were further micronized to include the various information requirements necessary to enable the flight crew to perform the task.

A winged helicopter was chosen for a candidate vehicle because this configuration was considered to have the performance characteristics desirable in the 1975-80 time period and because research available from other sources allowed a base for comparing studies and conclusions.

A flight crew of a pilot and copilot was used because the cost of an aircraft of this type and the importance of the various assigned missions requires operator backup to make sure the mission is completed and vehicle returned. Conventional instrumentation was referenced in this analysis as it was the only instrumentation available for study. It was beyond the scope of this study to consider other methods of presenting to the flight crew information about their aircraft's orientation in space. This limitation should not be interpreted as a recommendation for using conventional instrumentation. Any device that can present more accurate and more complete information to the flight crew should be considered as a candidate for flight instrumentation in new aircraft systems. The criteria should be to provide the flight crew with the greatest amount of needed information in the most rapid manner with a minimum of interfaces.

The analysis was based on the specific instruments that the pilots said they used or needed to perform the mission segment tasks.

The overall analysis was verified by flights in a UH-1 aircraft using an eye-movement camera to determine which instruments the pilot used to perform specific tasks and the total amount of time each instrument was used during the performance of the task.

¹ This study was a part of a program of research sponsored by the Avionics Laboratory, U. S. Army Electronics Command, to determine information requirements for the new generation of utility helicopters.

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METHOD

This study used USAAVLABS TR 68-39, A Study of Handling Qualities of Winged Helicopters (10) and the JANAIR Integrated Cockpit Research Program report of January 1967 (7) as a basis for the performance requirements and for the mission tasks. Each of the three missions was divided into the unique segments that would comprise that type of mission. These segments were further divided into the specific tasks required to accomplish them. The tasks were investigated as to the various motions, decisions, instruments, times, etc., to determine the information requirements of the crewmen. There were 96 separate tasks considered for the three missions; this method will allow the construction of other missions' information requirements according to the appropriate tasks identified in this study.

This initial analysis was completed by using existing information concerning the tasks, flight requirements, and instrumentation. This work was then presented to 11 pilots who had flown these types of missions in combat. Each pilot was asked to indicate the method he employed to perform the specific task; what instruments, if any, he used; and what instrumentation and/or information he felt he needed to perform the task properly. The replies were recorded on tape to facilitate the interviews and to ensure accuracy in reducing data. A standard set of 96 tasks was used by the interviewer.

To verify the analysis of crewmen's information requirements, several flights were concerned in a UH-1 during which the tasks analyzed were performed and the pilot's eye movements were recorded. The combination of these three approaches -- task analysis, interviews, and inflight validation -- was the basis for this report.

The 11 crewmen who acted as subjects in the interview phase of the study were highly experienced rotary wing pilots whose actual flight time in rotary wing aircraft ranged from 1000 hours to 10,000 hours. All were qualified and current in the UH-1 and several were qualified and current in the AH-1. Also in the group several that were qualified as instrument instructor/check pilots.

RESULTS

To relate this work to other efforts in the same area, the results of the flights and interviews will be presented in a format which is quite similar to that used by Ketchel and Jenney (6). The terms used and their definitions are as follows:

PITCH ANGLE	That component of attitude which provides the angle between the aircraft's longitudinal axis and the horizontal plane.
ROLL ANGLE	That component of attitude which provides the angle of the aircraft's rotation about its longitudinal axis.
ALTITUDE	Height above the surface and/or sea level.
AIRSPEED	Aircraft movement relative to the air mass along the heading vector.
STEERING	Heading necessary to make good a desired ground track.
ANGLE OF ATTACK	The acute angle between the longitudinal axis of the helicopter and a line representing the undisturbed relative airflow.
VERTICAL VELOCITY	Rate of climb or descent.
TURN RATE	Angular velocity during a turn (three degrees per second is a standard rate turn for aircraft considered in this study).
HOVER POSITION	Position in relation to desired reference point on the surface.
HOVER GROUND SPEED	Movement over the surface in any direction.
GROUND SPEED	Aircraft movement relative to the surface along the track vector.
TRACK	Path.
TORQUE	Power available.
RPM	Rotor and/or engine rotation speed.
ENGINE CONDITION	Engine and drive train information such as temperature and pressure readings that provide information on present engine operation.

The results of the interviews are shown in Table 1A. It will be noted that there are 21 tasks listed instead of the 96 tasks referenced previously; many of the tasks differed only slightly in parameters of performance from other similar tasks. When the results of the interviews were compiled, it was found that they could be presented using 21 actual flight tasks without loss of pertinent information. Table 1A indicates the percentage of the interviewees who stated that they would require information from a specific instrument or group of instruments to perform a given task within the specified performance parameters as well as the major source of information for the task. This study used the assumption that if an item was important enough to a pilot for him to be concerned about it, then it was an item about which he required information to perform the task at hand. Therefore, Table 1A can serve as a guide for providing to the pilot the information he requires.

The flight portion of the study included 21 of the tasks from the interview phase. These tasks were:

1. Spot Hover in Ground Effect, Visual
2. Spot Hover in Ground Effect, Instruments
3. Spot Hover Out of Ground Effect
4. 360-degree Hovering Turn Out of Ground Effect
5. Vertical Climb
6. Vertical Descent
7. Cruise, 60K, Visual
8. Cruise, 60K, Instruments
9. Standard Rate Turn, 60K
10. Climb, 60K, 500 Feet Per Minute
11. Climb from Hover
12. Initial Descent to 500 Feet; 60K (Approach)
13. Reverse Direction of Flight, 60K
14. Cruise, 100K, Visual
15. Cruise, 100K, Instruments
16. Standard Rate Turn, 100K
17. Terrain Following, 100K
18. Climb, 100K, 500 Feet Per Minute
19. Descent, 100K, 500 Feet Per Minute

20. 180-degree Descending Turn, 100K

21. Reverse Direction of Flight, 100K

Table 1A shows the response of the pilots interviewed to the above tasks. The numbers represent the percentage of the pilots that expressed a desire for information "information requirement" about the listed item in order to perform the task. The value given in the table referred to the use of a device presently installed in the UH-1 to provide the information or to a desired device to provide the information. Two categories which are not mentioned in other studies have been added to this table; they are the source of information used to perform the task:

EXTERNAL SOURCE -- information source is outside the cockpit.

INTERNAL SOURCE -- information source is inside the cockpit.

Hence for a task such as SPOT HOVER, we find that 91 percent of the pilot's information comes from an external source.

Table 2A presents the percentage of time the pilots used the various available sources of information while actually performing the tasks in the UH-1 helicopters. This data was obtained from eye-movement camera film taken during the time the pilots were actually flying the UH-1.

A task-by-task comparison of these two tables provides a clear indication of what the contemporary helicopter pilot feels his information requirements are and where he obtains this information.

In many cases it will be found that the sum of the part times exceeds 100 percent; this was due to the pilot fixating at a point in the flight instrument section of the instrument panel adjacent to several instruments and looking at more than one instrument without moving his fixation point. Hence, the data reflected that he was looking at more than one instrument (usually two) for that period of time.

It has been the attempt of this study to present to the reader the means by which contemporary pilots obtain the information required to perform the various tasks of the tactical utility helicopter mission. Many analytical studies have spelled out the information that a pilot needs to perform specific tasks and the time-line analysis of how and when he is supposed to use this information. While this is an excellent approach, this study wanted to determine where the pilot secures this information, what source of the several available to him he uses, how much of his time is used in securing this information, and what he looks at when he views the real world for cues to maintain his desired flight path. The results section has posed an answer to all of these propositions except the last, What does the pilot use for cues in the real world?, but an analysis of the eye-movement film and postflight talks with the subjects have provided the following information concerning these cues.

TABLE 1A

Percent Requirements
(Percent of subjects indication a requirement for specific information)

Task	Information	Pitch Angle	Roll Angle	Altitude	Airspeed	Steering	Angle of Attack	Vertical Velocity	Turn Rate	Hover Position	Over Ground Speed	Heading	Ground Speed	Track	Torque	RPM	Engine Condition	External Source	Internal Source
Spot Hover IGE Instructions		9	9	9						27	27	18	27		73	82	36	91	9
Spot Hover IGE Visual		9	9	73	27	91		9			27	55	27	36	36	36	27	82	18
Spot Hover OGE		36	36	55	18	91			18		9	73	9	18	64	64	27	91	9
360° Hovering Turn OGE		36	36	64		73		73			18	45	18	27	73	73	36	82	18
Vertical Climb		36	36	64	9	73						45		27	55	73	27	73	27
Vertical Descent		36	36	64		73		91						27	55	45	45	55	45
Cruise, 60K, Visual		73	73	91	100	100		82	36			82		27	55	45	36		100
Cruise, 60K, Instruments		91	91	91	100	100		91	36			91		36	55	45	36		100
Standard Rate Turn, 60K		100	100	100	100	100		73	82			82		36	27	27	18		100
Climb, 60K, 500 FPM		73	73	91	82	91		100	27			73		18	55	27	9		100
Climb from Hover		64	64	64	55	73		91	18			64		9	82	55	18		100
Initial Descent to 500 Feet		82	82	91	91	100	20	91	18		18	82	18	45	73	27	18	18	82
Reverse Dir. of Flight, 60K		82	82	64	73	45		18	91			36		9	64	45	27	36	64
Cruise, 100K, Visual		55	55	100	91	100		55	27			64		45	45	55	45	64	36
Cruise, 100K, Instruments		91	91	100	100	100		100	36			82		36	36	45	27		100
Standard Rate Turn, 100K		100	100	100	100	100		64	82			73		36	36	36	18		100
Terrain Following, 100K		9	9	45	45	55		9	45			45		9	45	27	18	100	
Climb, 100K, 500 FPM		73	73	82	91	91		100	27			73		18	55	27	18	18	82
Descent, 100K, 500 FPM		73	73	82	91	100	33	91	27			91		36	73	36	18		100
180° Descending Turn, 100K		91	91	100	73	100		91	100			82		27	45	27	18		100
Reverse Dir. of Flight, 100K		82	82	82	82	55		27	100			36		18	73	64	36	45	55

TABLE 2A

Percent of Time Pilots Used Specific Instruments While Performing Given Tasks in Actual Flight

Task	Instrument	Attitude Indicator	Altimeter	Airspeed Indicator	Compass	Vertical Velocity	Rate of Turn	Torque Meter	Dual Tachometer	Engine Instruments	External References
Spot Hover IGE Visual		3	2	1	2	2	1	2	2	1	85
Spot Hover IGE Instruments		25	12	7	18	12	3	15	13	11	
Spot Hover OGE		27	22	17	17	20	2	11	12	7	
360° Hovering Turn OGE		15	19	9	1	5		5	5	3	38
Vertical Climb		29	30	9	7	20	3	7	6	5	
Vertical Descent		4	5	4	3	1		2	4	7	75
Cruise, 60K, Visual		10	8	7	13	7	1	5	4	4	48
Cruise, 60K, Instruments		23	21	12	14	10	2	8	8	11	
Standard Rate Turn, 60K		23	18	9	19	9	7	6	6	6	
Climb, 60K, 500 FPM		19	17	11	19	19	2	8	6	7	
Climb from Hover		23	23	7	6	16	3	6	5	4	15
Initial Descent to 500', 60K		31	27	24	17	24		6	7	10	
Reverse Dir. of Flight, 60K		23	18	9	19	9	7	6	6	6	
Cruise, 100K, Visual		10	8	7	13	7	1	5	4	4	48
Cruise, 100K, Instruments		23	21	10	15	10	2	4	5	5	
Standard Rate Turn, 100K		14	25	2	25	14	1	3	3	3	
Terrain Following, 100K		2	2	2	2	2		2	2	2	85
Climb, 100K, 500 FPM		8	15	13	10	12	3	4	9	3	
Descent, 100K, 500 FPM		27	29	16	11	17	2	6	7	7	
180° Descending Turn, 100K		35	18	15	8	8	3	3	4	5	3
Reverse Dir. of Flight, 100K		14	25	2	25	14	1	3	3	3	

Hover IGE

The film indicated that the pilot was using an intersection of the left edge of the runway and a runway seam as a target; he was using the right-hand FM antenna as a sight-device to aim at this point. This arrangement provided him the pitch, roll, vertical velocity, and over-the-ground movement information. RPM and torque or power information was obtained in a semi-gross manner by monitoring aural and tactile sensation; the proper conditions feel and sound a certain way and deviations from these sounds and feel required a check of the instruments for specific information. Under conditions where a runway is not available, the pilot uses a terrain feature in the immediate area to provide the information ordinarily obtained from the runway edge-seam intersection.

Terrain Following and Cruise VFR

The real-world cues for these two tasks are quite similar with possibly a rate difference due to the lower height above the terrain of the Terrain Following task. Pitch and roll can be determined fairly accurately, while heading and altitude are less accurate, and velocity approaches the gross-information category. Again the general power and engine information is determined by aural and tactile sensation. When a pilot is questioned he says he uses the horizon as a reference; this may be true, but the eye movements filmed during the four flights which recorded the above tasks show that instead of the horizon the pilot fixates on a point and/or a line of terrain features, i.e., a relief line, parallel to the horizon and perpendicular to the flight path. This line was generally at a depression angle of 20 degrees.

Running Landing

While the subjects did not do this particular maneuver, the safety pilot did and they followed the maneuver. In this maneuver the right FM antenna was again used as a sight to line up on the runway centerline, and as the aircraft approached the runway the sighting target was shifted from the centerline to the left edge of the runway and remained there until touchdown. The information obtained is essentially the same as that for hover plus vertical rate of closure.

360-degree Hovering Turns; Hover OGE

These maneuvers are essentially the same as far as the real-world cues are concerned. The pilots appeared to pick out a relief feature to use as a reference point/line as they had done during the terrain following and cruise tasks and they used the point to determine yaw rate. This point was used as the point to start and to complete the turn on in the first instance and as the point to aim on to prevent yaw in the other.

Vertical Descent

A point on the ground was used to determine rate of closure/descent and as a general speed, yaw and attitude reference.

During all of the real-world cue tasks, approximately two percent of the time was spent cross-checking the instruments, with emphasis on the engine condition group. The use of the FM antenna as a sighting device has its origin in the gunnery tasks as a reference sight for rocker firing, according to the pilots interviewed, and its use as a general sighting device has persisted. It just happens that from the pilot's seat the use of this antenna as a sighting device provides accurate information concerning the heading of the aircraft.

Several information needs were evolved from the interviews that can be satisfied by instrumentation. The expression of a need for an over-the-ground movement indicator was almost universal. In the hover tasks and very slow speed tasks, there is no accurate information available to the pilot concerning his movement in relation to the ground. For rotary wing aircraft this information should be the value of the velocity vector in the horizontal plane. Several of the subjects expressed a desire for including the Torque and RPM indicators in the flight instrument group. This preference indicates that the information should be presented to the pilot in conjunction with the attitude, vertical velocity, and airspeed information now presented by the flight group. This type of presentation would reduce the scanning task load of the pilot.

The study has not included the information requirements of such areas as communications, armament, defenses, navigation, fuel management/cruise control, trim and radio/radar landing systems. Communication equipment and usage will depend upon future conditions and state-of-the-art, neither of which this study was equipped to handle. Armament and defense systems are in the same category as communications. Navigation was not listed as a separate requirement as the present equipment in the aircraft which is used for navigation (compass and airspeed indicator) was included. Future onboard navigation systems may change the source of navigation information but it is doubtful if the overall percentage of time usage will change. The fuel management/cruise control was a part of the engine condition information requirement. Trim was not applicable to the UH-1-B aircraft used for this study. Trim will be a consideration for a dual-rotor aircraft and possibly for single-rotor designs other than that used on the UH-1-B. Radio/radar landing systems for future aircraft will depend upon the state-of-the-art and on what is installed in the aircraft or at the ground station, or on both. The scope of this study was such that these items could not be included.

The portion of the time spent considering the real world was primarily concerned with keeping track of the aircraft's flight path, actual, desired, and projected, by constant cross-reference between map and ground checkpoints. The attitude of the vehicle in relation to a horizontal reference was also considered.

A pilot generally reports that he uses the horizon as his attitude reference, but from the film data obtained in this study, it was found that at low altitude (< 500 ft. absolute) the subjects consistently used a line on the ground which was essentially parallel to the horizon as a reference line for attitude and rate of closure.

Several items of information which would be required in specific flight phases have not been listed as yet in the study. Weather conditions enroute and at destination are required for safety. Fuel-management data is also certainly required information, as well as present position of the aircraft.

The subjects who had flight experience in the AH-1 expressed an opinion that this aircraft was much easier to fly than the UH-1, primarily because of its greater speed, but they said the information required to perform the given tasks was essentially the same.

SUMMARY

The study has shown what basic flight information the UH-1 pilot felt he needed to perform specific maneuvers and what instruments he used to obtain this information.

It has also determined what instruments the pilots actually used in flight to perform many of these tasks and the amount of time he spent using these instruments during each maneuver. Two missions of a tactical utility helicopter have been presented, maneuver by maneuver, and the estimated time spent using each of these instruments has been determined from experimental data. The need for certain information not now available with present instrumentation has been indicated. No attempt has been made to indicate in what form the various information should be presented nor have specialized areas such as armament, communications, defense, navigation, etc., been considered.

The techniques used in this study should be employed to expand the data base already established by increasing the sample size of the actual flight use of the displays now installed in U. S. Army helicopters. They should also be considered for the evaluation of new concepts such as the headup types, the contact-analog types, the television types, etc., and any other approach to information transfer that concerns the pilot of an aircraft, the operator of a vehicle, or the operator of any equipment where it is essential to present to the operator a large amount of data that must be visually screened to satisfactorily perform the desired task.

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APPENDIX B

LINK VALUES

The link values shown in the following tables are the percent of total fixation-point-to-fixation-point movements during the given maneuver that were between the identified link. As an example, the first entry in Table 1B is the link "Ahead Medium, Left Edge of the Runway" with a percent value of 22. This value indicates that 22 percent of the eye movements were between these two points. The breakouts of the directions of the movements are not given. The sums of the percentage values do not equal 100. These discrepancies were caused by rounding of values and by the loss of data due to unreadable film.

TABLE 1B

VFR Hover IGE

LINK	PERCENTAGE VALUE
AM, LERn;RM, LERn	22
AM, LERn;LM, LERn	18
RM, LERn;LM, LERn	11
RM, LERn;Power	11
AM, LERn;AN, CRn	11
AM, LERn;Engine Group	7
AM, LERn;AN, LERn	7
AN, CRn; Engine Group	4
AN, CRn; RN, CRn	4
AN, CRn; Engine Group	4

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TABLE 2B
IFR Hover IGE

LINK	PERCENTAGE VALUE
ATT ; PALT	1
ATT ; Pocket	1
ATT ; Power	2
ATT ; IAS/ATT	1
ATT ; PALT/VV	1
PALT ; SC	1
PALT ; PALT/ATT	1
PALT ; ATT/IAS	2
PALT ; PALT/VV	1
PALT ; VV/SC	5
VV ; Temp-slip	1
VV ; PALT/VV	1
VV ; ATT/PALT	5
VV ; SC/VV	1
Pocket ; ATT/PALT	8
Pocket ; VV/SC	2
Pocket ; SC	4
Pocket ; Clock	2
Pocket ; Power	4
Pocket ; ATT/IAS	4
Pocket ; PALT/VV	2
Pocket ; Temp-slip	2
Pocket ; VV	2
Engine Group ; Power	8
Engine Group ; ATT/IAS	1
Engine Group ; Temp-slip	2
Engine Group ; ATT/PALT	1
Power ; ATT/IAS	10
Power ; ATT/PALT	1
Power ; Temp-slip	1
ATT/PALT ; ATT/IAS	2
ATT/PALT ; PALT/SC	5
ATT/PALT ; Clock	1
ATT/IAS ; Temp-slip	2
Clock ; VV/SC	4
SC ; VV/PALT	1

TABLE 3B

Climb IFR

LINK	PERCENTAGE VALUE
ATT ; PALT	8
ATT ; IAS	7
ATT ; Pocket	4
ATT ; RMI	1
ATT ; RPM	1
ATT ; Engine Group	1
ATT ; Power	1
ATT ; ATT/IAS	1
ATT ; TQ	1
ATT ; PALT/VV	2
PALT ; IAS	3
PALT ; VV	12
PALT ; Pocket	5
PALT ; SC	1
PALT ; RMI	1
PALT ; RPM	2
PALT ; ATT/IAS	1
PALT ; VV/SC	2
IAS ; VV	1
IAS ; Pocket	3
IAS ; Engine Group	2
IAS ; RMI	1
IAS ; RPM	9
IAS ; TQ	1
IAS ; TS	1
IAS ; Temp-slip	1
VV ; Pocket	5
VV ; SC	1
VV ; Engine Group	1
VV ; RMI	1
VV ; ATT/IAS	1
VV ; PALT/SC	2
Pocket ; RMI	1
Pocket ; RPM	2
Pocket ; Power	1
Pocket ; PALT/VV	1
Engine Group ; RPM	1
Engine Group ; Power	3
Engine Group ; Temp-slip	1
Power ; Temp-slip	2
RPM ; TQ	3
RPM ; PALT/VV	1

TABLE 4B
Steep Climb VFR

LINK	PERCENTAGE VALUE
AM ; ARM	9
AM ; ALM	13
AM ; Engine Group	22
AM ; RN	4
AM ; RM	9
AM ; LN	4
AM ; AF	4
AM ; LM	4
ARM ; Engine Group	9
ARM ; LM	4
ARM ; RN	9
LM ; RM	4

TABLE 5B
Steep Climb IFR

LINK	PERCENTAGE VALUE
ATT ; IAS	8
ATT ; PALT	10
ATT ; Pocket	12
ATT ; SC	8
ATT ; VV	1
ATT ; RMI	1
ATT ; RPM	1
ATT ; Clock	1
ATT ; TS	1
PALT ; VV	10
PALT ; Pocket	9
PALT ; SC	4
VV ; SC	2
VV ; Pocket	1
VV ; IAS	1
VV ; Power	1
IAS ; RPM	5
IAS ; Pocket	1
IAS ; SC	1
IAS ; Engine Group	1
Pocket ; SC	3
Pocket ; Clock	1
Pocket ; Engine Group	1
Pocket ; TS	1
Pocket ; RPM	1
Pocket ; ATT/IAS	4
Pocket ; Power	6
Engine Group ; TS	1
RPM ; TS	2
RPM ; Engine Group	7
RPM ; SC	1
SC ; RMI	1

TABLE 6B

Cruise IFR

LINK	PERCENTAGE VALUE
ATT ; PALT	16
ATT ; IAS	8
ATT ; VV	2
ATT ; Pocket	5
ATT ; RMI	2
ATT ; Engine Group	2
ATT ; Power	2
ATT ; ATT/IAS	2
ATT ; IAS/RPM	1
ATT ; ATT/PALT	1
PALT ; IAS	2
PALT ; VV	5
PALT ; Pocket	9
PALT ; SC	5
PALT ; ATT/IAS	2
PALT ; VV/SC	2
IAS ; RMI	1
IAS ; Engine Group	1
IAS ; Power	5
IAS ; Pocket	1
VV ; Pocket	3
VV ; SC	2
VV ; RMI	1
VV ; PALT/VV	1
Pocket ; SC	1
Pocket ; Clock	1
Pocket ; RMI	2
Pocket ; Power	1
Pocket ; ATT/PALT	2
Pocket ; PALT/VV	1
Pocket ; Temp-slip	1
Engine Group ; Power	8
Engine Group ; Temp-slip	2
Engine Group ; IAS/RPM	2
Power ; ATT/IAS	1
Power ; Temp-slip	2
ATT/PALT ; ATT/IAS	1

TABLE 7B
180-Degree Turn IFR

LINK	PERCENTAGE VALUE
ATT ; PALT	15
ATT ; IAS	5
ATT ; VV	1
ATT ; Pocket	4
ATT ; Engine Group	4
ATT ; Power	1
ATT ; RMI/TS	5
ATT ; ATT/IAS	1
ATT ; PALT/VV	4
PALT ; IAS	1
PALT ; VV	4
PALT ; Pocket	9
PALT ; Engine Group	1
PALT ; Power	1
PALT ; RMI/TS	4
PALT ; SC	4
PALT ; Temp-slip	1
PALT ; VV/SC	1
PALT ; Clock	1
IAS ; VV	2
IAS ; Pocket	4
IAS ; Engine Group	2
IAS ; Power	4
IAS ; Temp-slip	1
VV ; Pocket	4
VV ; RMI/TS	1
VV ; PALT/VV	1
VV ; SC	1
Pocket ; Engine Group	2
Pocket ; RMI/TS	3
Pocket ; SC	1
Pocket ; Clock	1
Engine Group ; Power	3
Engine Group ; Temp-slip	1
Engine Group ; TS	1
Power ; Temp-slip	1
Power ; PALT/VV	1
RMI/TS ; ATT/IAS	1
RMI/TS ; PALT/VV	1

TABLE 8B
Steep Approach IFR

LINK	PERCENTAGE VALUE
ATT ; PALT	14
ATT ; IAS	7
ATT ; VV	2
ATT ; Pocket	8
ATT ; Power	1
ATT ; ATT/IAS	2
ATT ; ATT/PALT	1
PALT ; IAS	2
PALT ; VV	12
PALT ; Pocket	4
PALT ; SC	2
PALT ; ATT/PALT	1
PALT ; Engine Group	1
PALT ; Power	1
PALT ; ATT/IAS	3
PALT ; VV/SC	2
IAS ; VV	1
IAS ; Pocket	2
IAS ; Engine Group	2
IAS ; Power	5
IAS ; ATT/IAS	1
IAS ; RPM	1
VV ; Pocket	5
VV ; PALT/VV	1
Pocket ; ATT/IAS	2
Engine Group ; Power	4
Engine Group ; ATT/IAS	2
Engine Group ; RPM	1
Power ; TS	1
Power ; ATT/IAS	2
SC ; VV/PALT	1

TABLE 98
180-Degree Descending Turn

LINK	PERCENTAGE VALUE
ATT ; IAS	5
ATT ; PALT	24
ATT ; VV	6
ATT ; Pocket	5
ATT ; Engine Group	3
ATT ; ATT/IAS	7
ATT ; TS	2
ATT ; RMI	1
ATT ; RPM	1
ATT ; Power	1
PALT ; VV	8
PALT ; Pocket	2
PALT ; ATT/IAS	2
PALT ; Engine Group	1
IAS ; Power	7
IAS ; VV	3
IAS ; Pocket	3
IAS ; Engine Group	3
IAS ; ATT/IAS	3
IAS ; RPM/IAS	2
VV ; Pocket	5
VV ; ATT/IAS	2
Pocket ; RMI	1
Pocket ; ATT/IAS	1
Engine Group ; RPM/IAS	2
Engine Group ; RMI	1
Engine Group ; Power	1
Power ; ATT/IAS	1
RMI ; TS	1

TABLE 108

180-Degree Hovering Turn OGE

LINK	PERCENTAGE VALUE
ATT ; IAS	3
ATT ; PALT	4
ATT ; RPM	1
ATT ; ATT/IAS	1
ATT ; RN	1
ATT ; RM	1
ATT ; AN	4
PALT ; IAS	1
PALT ; VV	1
PALT ; Pocket	1
PALT ; ATT/PALT	2
PALT ; RM	2
PALT ; RN	10
PALT ; FRN	2
IAS ; Power	5
IAS ; RPM	2
IAS ; AT ² /IAS	1
IAS ; Engine Group	1
IAS ; ATT/PALT	1
IAS ; FRN	2
IAS ; RN	1
VV ; RN	1
Pocket ; ATT/IAS	1
Pocket ; ATT/PALT	1
Engine Group ; Power	1
Engine Group ; RPM	1
Engine Group ; LN	1
Engine Group ; RN	1
Power ; AN	2
Power ; FRN	1
RN ; ATT/IAS	1
RN ; ATT/PALT	2
RN ; AN	9
RN ; FRN	11
RN ; RFH	1
RM ; FRM	1
FRN ; ATT/PALT	4
FRN ; Power	1
FRN ; AN	2
FRN ; LN	2
FRFH ; AN	1
FRFH ; RFH	1
FRM ; AM	2
LFH ; AFH	2
LFH ; AFH	2
LFH ; RFH	1
AFH ; RFH	2
AN ; LN	2

TABLE 11B
IFR Hover OGE

LINK	PERCENTAGE VALUE
ATT ; Power	1
ATT ; VV	1
ATT ; PALT	26
ATT ; IAS	8
ATT ; Pocket	8
PALT ; VV	10
PALT ; Engine Group	1
PALT ; Power	3
PALT ; Pocket	9
PALT ; IAS	2
PALT ; ATT/IAS	1
IAS ; Power	10
IAS ; Engine Group	1
IAS ; ATT/IAS	1
VV ; Pocket	5
Engine Group ; Temp-slip	1
Engine Group ; Power	5
Power ; ATT/IAS	2
Power ; Temp-slip	3

TABLE 12B

Vertical Descent

LINK	PERCENTAGE VALUE
ATT ; PALT	6
ATT ; IAS	3
ATT ; VV	1
ATT ; Pocket	3
ATT ; Temp-slip	1
ATT ; ATT/IAS	1
ATT ; AN	1
ATT ; RN	1
PALT ; IAS	4
PALT ; VV	4
PALT ; Pocket	3
PALT ; Power	1
PALT ; SC	1
PALT ; ATT/PALT	1
PALT ; ATT IAS	1
PALT ; AN	1
PALT ; RN	1
PALT ; FRN	1
IAS ; Pocket	3
IAS ; Engine Group	1
IAS ; Power	6
IAS ; RMI	1
IAS ; ATT/IAS	3
IAS ; AN	1
VV ; Pocket	3
VV ; RMI	1
VV ; RN	1
Pocket ; Engine Group	1
Pocket ; PALT/VV	1
Pocket ; AN	1
Pocket ; RN	1
Engine Group ; Power	4
Engine Group ; Temp-slip	1
Engine Group ; AN	1
Power ; Temp-slip	3
Power ; ATT/IAS	1
RMI ; ATT/IAS	1
RMI ; LN	1
ATT/PALT ; ATT/IAS	1
ATT/PALT ; LN	1
AN ; R	3
AN ; RN	6
AN ; LN	1
AN ; PALT/VV	1
RN ; LN	3
RN ; FRN	1

TABLE 13B
Low Level Cruise IFR

LINK	PERCENTAGE VALUE
ATT ; IAS	4
ATT ; PALT	5
ATT ; Pocket	4
ATT ; RMI	3
ATT ; ATT/IAS	4
ATT ; PALT/VV	7
ATT ; Power	2
ATT ; Temp-slip	1
PALT ; VV	4
PALT ; Pocket	5
PALT ; IAS	1
PALT ; Power	2
PALT ; ATT/IAS	2
PALT ; PALT/VV	2
IAS ; Power	6
IAS ; Temp-slip	2
IAS ; Pocket	1
IAS ; Engine Group	2
IAS ; ATT/IAS	1
VV ; Pocket	4
VV ; RMI	2
VV ; PALT/VV	2
VV ; Clock	2
Pocket ; RMI	3
Pocket ; PALT/VV	5
Pocket ; ATT/IAS	2
Engine Group ; Power	6
Engine Group ; Temp-slip	1
Engine Group ; ATT/IAS	1
ATT/IAS ; Power	4
ATT/IAS ; Temp-slip	1
ATT/IAS ; Clock	1
Temp-slip ; Power	2
Temp-slip ; RMI	2

TABLE 14B
Terrain Following

LINK	PERCENTAGE VALUE
AM ; LN	5
AM ; RN	5
AM ; ARM	7
AM ; RM	1
AM ; FRM	2
AM ; ALM	4
AM ; LM	1
AM ; AN	2
AN ; ALN	1
AN ; RN	5
ARM ; LN	2
ARM ; Engine Group	1
ARM ; RM	5
ARM ; ALM	1
ARM ; RN	1
ARM ; ALM	1
RM ; ALM	2
RM ; RN	4
RM ; LN	1
RM ; FRM	10
RM ; ALN	1
LN ; ALM	1
LN ; AN	2
LN ; ALN	6
LN ; Engine Group	2
LN ; LM	4
RN ; AM	1
RN ; AR	1
AM ; FRF	2
AM ; FRN	2
ALM ; FRM	1
ALM ; AL	2
ALM ; LM	4
LM ; ALN	1

APPENDIX C

USE OF THE EMC-2 EYE-MOVEMENT CAMERA

The techniques presented in this section were developed by the author and Mr. Mark J. Monahan. The EMC-2 camera used in this experiment was on loan from the U. S. Air Force, AMRL, MRHR, Wright-Patterson Air Force Base, Ohio. This instrument was furnished with a medium and a large APH-6A Air Force flight helmet adapted for the camera system rather than the Guardian motorcycle helmet recommended by the manufacturer (The Westgate Laboratory, Inc., 506 S. High St., Yellow Springs, Ohio). Figure 1C shows the system as used in the initial stages of this study.

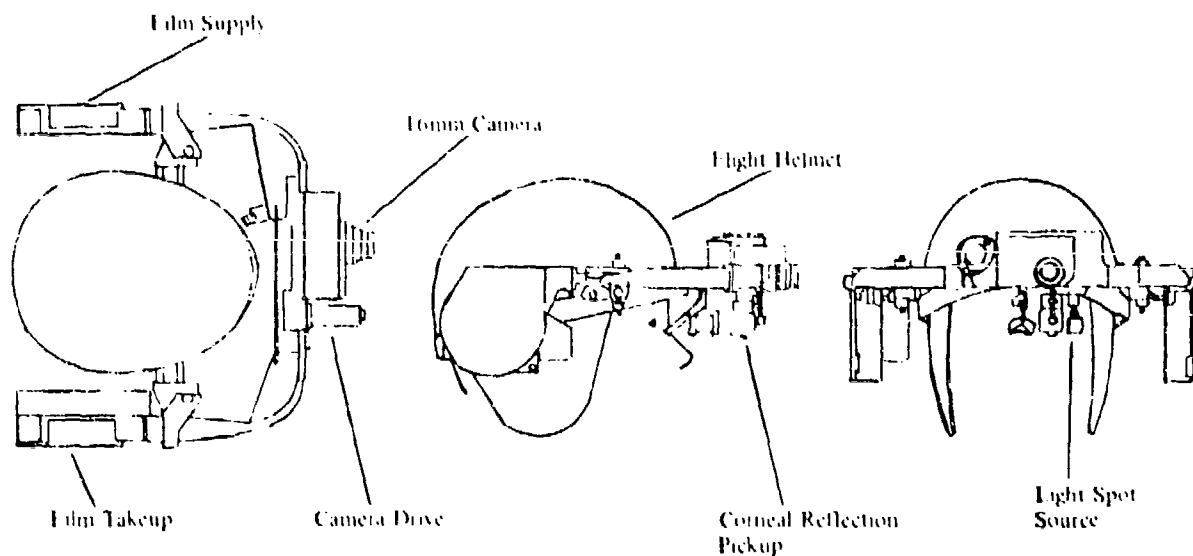


Fig. 1C. EYE-MOVEMENT CAMERA SYSTEM

The following description of the system was provided by the manufacturer:

WESTGATE EYE-MOVEMENT CAMERA

The model EMC-2 Camera is a light-weight, completely self contained, head-mounted, 16mm motion picture data recording system for research, training and diagnostic study of eye-fixation and scanning characteristics.

As the wearer observes a scene, the camera accurately records the points of instantaneous eye fixation. Analysis of the projected film makes it possible to correlate eye movements with various stimuli, and with concurrent measurements of other responses.

In industry and military applications the camera serves as a tool for vigilance studies, training programs, human engineering and product development. Human reactions to real traffic problems, textual materials, packaging, advertising and color patterns can be accurately recorded and analyzed. In medicine the camera can be a tool for diagnostic study of brain damage and the effects of drugs. It also provides a means of recording reading and scene-scanning defects in individuals. Complete portability of the Eye-Movement Camera permits its use in both field and laboratory -- practically any place where it is necessary to study eye-movement characteristics. This unique system is currently in use by the armed forces, space research laboratories and leading research organizations.

Principle of Operation

The camera is fixed to a helmet worn on the subject's head. As the camera photographs the subject's field of view, or primary image, a secondary image is superimposed on the film in the form of a small white dot. In each frame the dot indicates the exact point of eye fixation at the instant of exposure. The secondary image is created by the corneal reflection of a pinpoint light trained on the subject's left eye. The reflected spot is imaged on the back of the film and superimposed on the primary image. At the film plane, the reflected spot can be as small as 0.13 inch in diameter. Larger spot sizes can be achieved by changing the aperture mask.

The shape of the cornea causes the position of the reflected light to change with eye movement, accurately indicating the point of instantaneous eye fixation.

Camera System

The electrically operated camera system is in the form of a horseshoe, with film supply and take-up spools located on either side of the head. The spools hold up to 125 feet of film. Speed is adjustable to 4, 8 or 16 frames per second. Speeds to 100 frames per second can be provided. Recording time is 21 minutes at four frames per second.

The system is easily controlled by the subject or investigator with a hand held control box, containing switches to regulate power, camera speeds and light source intensity. Power is supplied either by a battery strapped to the subject's waist or by an external source.

For convenience in conducting experiments, a switch closure with each frame is provided to synchronize the camera data with voice recordings, oscillographs and other forms of recorded information.

It is possible to determine which instrument is being viewed in an aircraft cockpit, or which sign or vehicle is the point of attention in a driver study. Special lenses provide even greater detail showing the instrument portion, or particular letter being viewed in a line of text.

Data can be reduced rapidly with a 16mm projector or editing viewer.

Calibration and Adjustment

The camera and helmet can be adjusted laterally, longitudinally and rotationally to fit each subject's anthropometric requirements. The nose steady-rest is also adjustable. If the camera and helmet must be removed and replaced often during an experiment, or if excessive head motion may be encountered, the optional bite bar is necessary in order to maintain calibration.

A Calibration Viewer, VC-1, attaches to the camera in place of the primary scene lens to permit adjustment and calibration of image alignments for the entire field of view.

An Alignment Check Viewer provides a means of retaining the subject's basic adjustments if the helmet must be removed. When the helmet is replaced, the subject may rapidly reproduce the previous position.

When telephoto lenses are used for greater detail and accuracy, the adjustable bite bar is recommended.

Calibration Stand

The Calibration Stand, an optional accessory, provides a practical and safe means for supporting the camera and helmet for film loading and unloading, initial calibration, training, storage or test purposes.

SPECIFICATIONS

Camera

Custom designed, electrically driven, 16mm motion picture camera. Frame rates adjustable to 4, 8 and 16 frames per second. Rates to 100 frames per second are available on special order. Camera without helmet and film weighs 3.9 pounds.

Film

Capacity of 100 feet standard 16mm film, or 125 feet of Dupont Kronar base film. Maximum recording time 21 minutes at 4 frames per second.

Lens

Five element f/2.2 lens with 10mm focal length. Capable of resolving scene elements separated by less than one-degree of arc. Field of view 20 degrees from nominal line of sight. Other lenses, including wide-angle, may be used.

Helmet

Camera is normally mounted on a Guardian motorcycle safety helmet. Basic camera is readily adaptable to other commercial and military helmets.

Electrical

Input power 28 volts DC supplied to control box from external source or battery strapped to subject's waist. Current drain is 1.24 amperes.

HEL CALIBRATION PROCEDURES

The accurate calibration of the system is essential for obtaining successful results. For the study a camera-to-panel distance of 24 inches was used. This distance was representative of the eye-to-panel distances encountered in the aircraft used.

The calibration chart constructed consisted of cross-hairs and two square rings: the inner ring was 3.2 inches on a side and the outer ring was six inches on a side. These measurements were determined by calculations using the optical specifications of the camera tempered by a dash of cut-and-fit technique. A chart this size used for calibration effectively covers the maximum recordable scan area of the system. To produce the calibration strips of film which must be in the film gate of the camera for initial calibration, a target was constructed in the same design as the calibration chart with the following dimensions: cross-hair lines were $\frac{1}{4}$ inch Black ChartPak, the inner ring was 8.625 inches on a side and made of $\frac{1}{2}$ inch Black ChartPak, and the outer ring was 15.75 inches on a side and made of $\frac{1}{2}$ inch Black ChartPak. The target background was white poster board and was placed 24 inches from the rear element in the lens system of the camera.

The first step in calibrating this system is to make sure the boresight light from the camera is actually indicating the center of the target. This was done by placing the camera in the calibration stand and centering the boresight light on the center of the target. Several feet of film was then exposed and the picture of the target was checked against the center of the picture frame. Slight adjustments can be made in the boresight light by the use of shims at the mounting points.

Calibrating the system for use required a snug but comfortable fit of the helmet and adjustment of the camera helmet mounts so that there was sufficient movement of the periscope in the vertical direction to accommodate the subject's eye.

Prior to an actual run with the system, a calibration leader strip was attached to the film and loaded into the camera. This film was advanced through the camera until all drive sprockets contained film. The lens was then removed and a frame of the calibration strip was stopped and centered in the film gate with the shutter in the open position. The system was then put on the subject. When the helmet was properly donned and the helmet chin strap fastened, the bite-bar attachment was adjusted to the subject and the light source was adjusted to project a dot of light on the subject's cornea.

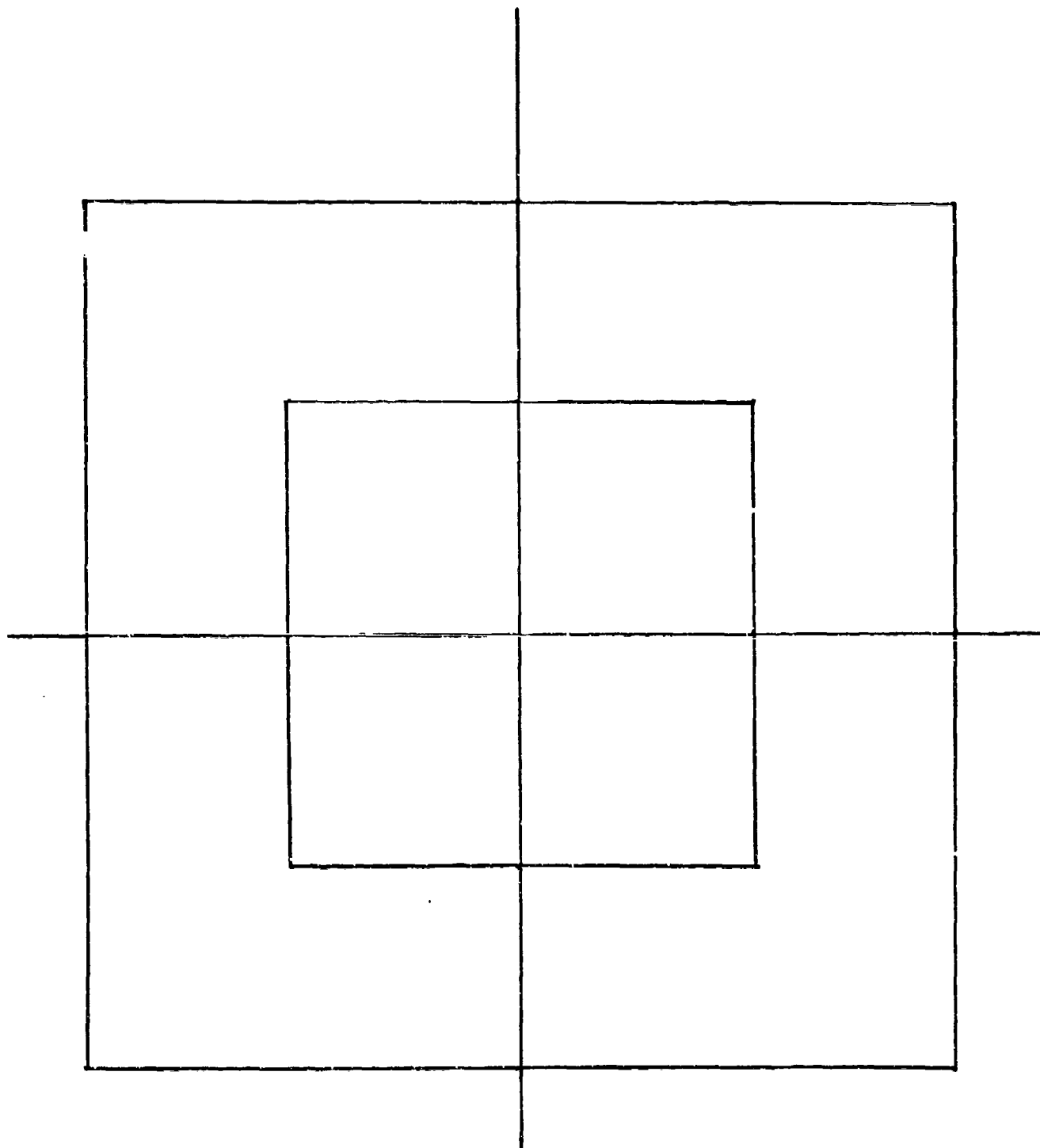


Fig. 2C. EMC-2CALIBRATION CHART

The experimenter now installed the VC-1 Calibration Viewer in the camera in place of the lens so that he might adjust the periscope to provide the proper size light spot reflected from the eye onto the calibration strip of film in the film gate. The instructions furnished with the system cover this step in detail. The subject was then instructed to look at the calibration chart, which was approximately 24 inches in front of him, and to aim his head so that the boresight light coincided with the intersection of the cross-hairs. He was then instructed to fixate on this point while the experimenter checked through the VC-1 to see if the reflected light from the cornea was also in the center of the calibration strip of film; if it was not, the periscope was adjusted to place it there. When this adjustment was accomplished, the subject was instructed to look at the lower left corner of the inner sighting ring; if the calibration was correct the dot of light on the calibration strip of film moved to the upper right corner of the inner ring. This step was repeated for all four corners of both of the sighting rings and adjustments made if necessary. When this procedure was completed, the VC-1 was removed and the lens was installed in the camera. The initial calibration of a subject, after the helmet had been fitted, took an experienced operator 15-20 minutes; subsequent calibrations on the same subject took approximately five minutes.

Early in the study it was determined that the nose steady-rest was not usable for an experiment of this type. The Design Engineering Branch of the Human Engineering Laboratory developed a lightweight bite-bar attachment which used the nose steady-rest mounting points and offered no visual interference. LTC K. L. Miller, Chief of Prosthetics, U. S. Army Dental Detachment at Aberdeen Proving Ground, Md., provided fitted acrylic bite bars for this attachment. These bite bars were fitted to the subject's upper and lower front teeth from canine to canine and were bonded to the metal portion of the bite bars (Figs. 3C and 4C).



Fig. 3C. PILOT S WEARING EMC-2

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Fig. 4C. PILOT H WEARING EMC-2

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It was felt that the successful use by the study of the EMC-2 system in actual helicopter flight depended on these bite bars. They allowed for quick and accurate calibration; once calibrated it was possible for the subject to make gross and rapid head movements without changing calibration. It was also possible for the subject to open his mouth without disturbing the calibration; and, of special importance, subject discomfort was minimized. There were no complaints from the subjects during or after any of the six flights; the subjects kept the helmets on and bite bars in place in all cases until the aircraft had landed and was shut down, even though they had been instructed that they could remove the bite bar as soon as the safety pilot took control of the aircraft. The subjects averaged slightly more than one-half hour of system-wearing time for each 20 minute flight.

Problems encountered and documented by other users of this system were known prior to its use in this test, but it was felt that the EMC-2 system was the most appropriate one available for this study because it offered simplicity of data reduction. The HEL-designed bite bars allowed us to secure data where others had encountered insurmountable difficulties. A minor modification of the film-transport system eliminated the film breakage experienced by others. An improved technique for cutting the leading edge of the film was developed to shorten the loading time from more than 30 minutes to two minutes.

One problem the study did not overcome concerned the aperture settings necessary to secure readable film. If the aperture (f) setting was proper for the ambient light and shutter speed used, the exposed film would not show the dot indicating eye-fixation point. To correct for this an aperture of four f settings greater was used; for example, if the light and shutter speed called for a setting of f 2.2, with aperture settings of f 2.2, f 3.5, f 5.6 and f 8 available, a setting of f 8 was necessary to have both the scene and eye-fixation dot visible and usable on the film. The study used Plus X Reversal film which has a rather thick and opaque emulsion through which the eye-fixation light must penetrate. There are films available which have an essentially transparent emulsion and should alleviate this problem.

Another problem considered was the adverse effect of the aircraft's vibration on photography. Previous experimentation by the Human Engineering Laboratory in the OH-6 helicopter used a motion picture photography of the instrument panel during flight for recording instrument readings. The vibration in this case caused little or no difficulty in reading the instruments; but to be prepared for the worst possible conditions, a small bracket was designed to damp the vibrations of the eye-movement camera. This bracket, constructed from 20-gauge steel, was a quarter-inch wide by two inches long and was secured to the camera frame by the nose steady-rest mounting bolts. It had a rubber pad bonded to the other end, which was in contact with the helmet; this friction provided vibration damping. In actual flight it was not necessary to use this device, since the vibration damping action of the pilot's neck was sufficient to take care of any motion encountered in the UH-1.

APPENDIX D

DATA CONVERSIONS

Data for Tables 1D through 21D were compiled from USAF documents and the source of each table or set of tables is shown above the table number and title. Tr represents the time in seconds required to complete the listed maneuver. TR = Tr x Ss, the time to complete one maneuver multiplied by the number of subjects.

USAF TR 5839 EYE FIXATIONS OF AIRCRAFT PILOTS, II

TABLE 1D
ILAS Approach

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	1385	.52	.29	.15	720
Directional Gyro	2143	.56	.45	.25	1200
PALT	253	.38	.05	.02	96
VV	246	.39	.05	.02	96
IAS	1263	.38	.26	.10	480
TS	141	.34	.03	.01	48
Engine Group	121	.79	.02	.02	96
APT	2288	.86	.48	.41	1968

Ss = 40, Tr = 120, TR = 4800

USAF TR 6957 EYE FIXATIONS OF AIRCRAFT PILOTS, III

TABLE 2D
GCA Approach

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	1629	.56	.34	.19	912
Directional Gyro	2613	.90	.54	.49	2352
PALT	369	.39	.08	.03	144
VV	511	.47	.11	.05	240
IAS	1432	.57	.30	.17	817
TS	267	.36	.06	.02	96
Engine Group	218	.88	.04	.04	192
XPT	0	0	0	0	0

Ss = 40, Tr = 120, TR = 4800

USAF TR 5975 EYE FIXATIONS OF AIRCRAFT PILOTS, IV

TABLE 3D

IFR Climb

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	929	.59	.43	.24	518
Directional Gyro	860	.51	.40	.20	432
PALT	346	.47	.16	.07	151
VV	428	.47	.20	.09	194
IAS	803	.67	.37	.24	518
TS	180	.39	.08	.03	65
Engine Group	191	1.13	.09	.10	216

Ss = 36, Tr = 60, TR - 2160

TABLE 4D

IFR Descent

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	900	.54	.42	.22	475
Directional Gyro	882	.54	.31	.21	454
PALT	313	.48	.14	.07	151
VV	385	.49	.18	.08	173
IAS	792	.67	.37	.24	518
TS	137	.34	.06	.03	65
Engine Group	230	1.25	.11	.12	259

Ss = 36, Tr = 60, TR = 2160

USAF TR 5975 EYE FIXATIONS OF AIRCRAFT PILOTS, IV

TABLE 5D
IFR Climbing Turn

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	886	.70	.41	.18	605
Directional Gyro	940	.56	.43	.23	497
PALT	371	.44	.17	.07	151
VV	360	.48	.17	.08	173
IAS	626	.58	.29	.16	346
TS	230	.48	.11	.05	108
Engine Group	191	1.11	.09	.09	194

Ss = 36, Tr = 60, TR = 2160

TABLE 6D
IFR Descending Turn

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	889	.63	.41	.25	540
Directional Gyro	914	.59	.42	.24	518
PALT	320	.45	.15	.06	130
VV	324	.46	.15	.07	151
IAS	677	.61	.31	.19	410
TS	241	.46	.11	.05	108
Engine Group	198	1.13	.09	.10	216

Ss = 36, Tr = 60, TR = 2160

USAF TR 5975 EYE FIXATIONS OF AIRCRAFT PILOTS, IV

TABLE 7D
IFR Level Turn

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	947	.70	.44	.29	626
Directional Gyro	961	.60	.44	.26	562
PALT	544	.50	.25	.12	259
VV	338	.39	.16	.06	130
IAS	533	.52	.25	.12	159
TS	288	.44	.13	.06	130
Engine Group	90	.93	.04	.04	86

Ss = 36, Tr = 60, TR = 2160

TABLE 8D
IFR Level Flight

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	458	.91	.38	.25	300
Directional Gyro	518	.91	.43	.37	444
PALT	274	.60	.23	.13	156
VV	132	.46	.11	.05	60
IAS	136	.64	.11	.07	84
TS	88	.44	.07	.03	36
Engine Group	18	1.49	.01	.02	24

Ss = 10, Tr = 120, TR = 1200

USAF TR 6018 EYE FIXATIONS OF AIRCRAFT PILOTS, V

TABLE 9D

IFR Standard Rate Turn

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	300	.82	.25	.20	246
Directional Gyro	348	1.03	.29	.30	358
PALT	156	.47	.13	.06	73
VV	36	.58	.03	.02	21
IAS	36	.52	.03	.02	19
TS	252	.85	.21	.18	214
Engine Group	0	0	0	0	0
Clock	240	.80	.20	.16	192

Ss = 10, Tr = 120, TR = 1200

USAF TR 6570 EYE FIXATIONS OF AIRCRAFT PILOTS, VI

TABLE 10D

Day ILAS Approach

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	535	.37	.30	.11	198
Directional Gyro	667	.54	.37	.20	360
PALT	95	.38	.05	.02	36
VV	231	.39	.13	.05	90
IAS	257	.49	.14	.07	126
TS	--	--	--	--	--
Engine Group	81	.89	.04	.04	72
XPT	1066	.76	.59	.45	810

Ss = 15, Tr = 120, TR = 1800

USAF TR 6570 EYE FIXATIONS OF AIRCRAFT PILOTS, VI

TABLE 11D
Night ILAS Approach

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	270	.40	.15	.06	108
Directional Gyro	491	.66	.28	.18	324
PALT	82	.44	.04	.02	36
VV	170	.53	.09	.05	90
IAS	262	.55	.14	.08	144
TS	--	--	--	--	--
Engine Group	41	.89	.02	.02	36
XPT	819	1.23	.45	.56	1008

USAF TR 6709 EYE FIXATIONS OF AIRCRAFT PILOTS, VII

TABLE 12D
Day GCA Approach

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	478	.49	.26	.13	234
Directional Gyro	845	.98	.47	.46	828
PALT	150	.36	.08	.03	54
VV	613	.47	.34	.16	288
IAS	367	.54	.20	.11	198
TS	--	.29	--	--	--
Engine Group	80	1.13	.04	.05	90
XPT	--	.18●	--	--	--

Ss = 15, Tr = 120, TR = 1800

USAF TR 6709 EYE FIXATIONS OF AIRCRAFT PILOTS, VII

TABLE 13D

Night GCA Approach

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	267	.54	.15	.08	144
Directional Gyro	697	1.24	.39	.48	864
PALT	167	.43	.09	.04	72
VV	496	.69	.27	.19	342
IAS	360	.70	.20	.14	252
TS	--	.18	--	--	--
Engine Group	36	1.00	.02	.02	36
XPT	50	.36	.03	.01	18

Ss = 15, Tr = 120, TR = 1800

WADC TR 52-17 EYE FIXATIONS OF AIRCRAFT PILOTS, VIII

TABLE 14D

Zero-Reader Approach

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	162	.48	.27	.13	78
Directional Gyro	14	.50	.02	.01	7
PALT	14	.42	.02	.01	6
VV	27	.45	.04	.02	12
IAS	104	.52	.17	.09	54
TS	17	.70	.03	.02	12
ZERO-READER	298	1.29	.50	.64	384
XPT	16	.25	.03	--	4
RPM	36	.66	.06	.04	24
EGT	15	.48	.02	.01	7

Ss = 10, Tr = 60, TR = 600

WADC TR 53-220 EYE FIXATIONS OF AIRCRAFT PILOTS, IX

TABLE 15D

Day -- Level Turn

INSTRUMENT	Ni	\overline{Td}	\overline{is}	n	Ti
Gyro Horizon	357	.73	.40	.29	261
Directional Gyro	306	.47	.34	.16	144
PALT	368	.44	.41	.18	162
VV	332	.38	.37	.14	126
IAS	129	.49	.14	.07	63
TS	103	.61	.11	.07	63
Engine Group	32	.85	.03	.03	27
XPT	33	.27	.04	.01	9

Ss = 15, Tr = 60, TR = 900

TABLE 16D

Night -- Level Turn

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	349	.86	.35	.30	314
Directional Gyro	197	.64	.22	.14	126
PALT	300	.63	.33	.21	189
VV	225	.52	.25	.13	117
IAS	155	.64	.17	.11	99
TS	91	.79	.10	.08	72
Engine Group	19	.94	.02	.02	18
XPT	35	.26	.04	.01	9

Ss = 15, Tr = 60, TR = 900

WADC TR 53-220 EYE FIXATIONS OF AIRCRAFT PILOTS, IX

TABLE 17D

Day -- Straight and Level

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	252	.50	.28	.14	126
Directional Gyro	409	.66	.45	.30	270
PALT	372	.46	.41	.19	171
VV	277	.39	.31	.12	108
IAS	200	.54	.22	.12	108
TS	20	.46	.02	.01	9
Engine Group	47	.96	.05	.05	45
XPT	72	.25	.08	.02	18

Ss = 15, Tr = 60, TR = 900

TABLE 18D

Night -- Straight and Level

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	278	.58	.31	.18	162
Directional Gyro	318	.82	.35	.29	261
PALT	321	.56	.36	.20	180
VV	240	.45	.27	.12	108
IAS	180	.70	.20	.14	126
TS	17	.54	.02	.01	9
Engine Group	12	.76	.01	.01	9
XPT	82	.33	.09	.03	27

Ss = 15, Tr = 60, TR = 900

WADC TR 53-220 EYE FIXATIONS OF AIRCRAFT PILOTS, IX

TABLE 19D

Climbing Turn, New Panel

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	343	.63	.38	.24	216
Directional Gyro	267	.54	.30	.16	144
PALT	171	.42	.19	.08	72
VV	413	.61	.46	.28	252
IAS	221	.53	.25	.13	117
TS	18	.49	.02	.01	9
Engine Group	55	.99	.06	.06	54
XPT	43	.21	.05	.01	9
Clock	24	.38	.03	.01	9

Ss = 15, Tr = 60, TR = 900

TABLE 20D

180-Degree Timed Turn, New Panel

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	336	.67	.37	.25	225
Directional Gyro	388	.51	.43	.22	198
PALT	321	.42	.36	.15	135
VV	275	.36	.31	.11	99
IAS	100	.45	.11	.05	45
TS	60	.60	.07	.04	36
Engine Group	24	.75	.03	.02	18
XPT	36	.25	.04	.01	9
Clock	15	.60	.02	.01	9

Ss = 15, Tr = 60, TR = 900

WADC TR 53-220 EYE FIXATIONS OF AIRCRAFT PILOTS, IX

TABLE 21D

Constant HDG Descent, New Panel

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	340	.45	.38	.17	153
Directional Gyro	289	.56	.32	.18	162
PALT	110	.41	.12	.05	45
VV	585	.40	.65	.26	234
IAS	300	.63	.33	.21	189
TS	15	.58	.02	.01	9
Engine Group	70	1.23	.08	.08	72
XPT	75	.24	.08	.02	18

Ss = 15, Tr = 60, TR - 900

The following information, Tables 22D through 28D, are taken from "Pilot Eye Fixations While Flying Selected Maneuvers Using Two Instrument Panels" by C. A. Gainer and R. W. Obermayer. They present data from the conventional instrument panel only.

TABLE 22D

Low Approach

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Attitude Ind.	401	.36	.42	.15	145
Heading Ind.	411	.52	.43	.22	213
PALT	120	.47	.12	.06	56
VV	175	.38	.18	.07	66
XPT	155	.45	.16	.07	71
ILS	128	.20	.13	.04	38
Other	13	.32	.01	--	4
Nu *	868	.42	.90	.38	367

Ss = 16, Tr = 60, TR = 960

*Nu denotes fixations not accounted for, blinks, etc.

TABLE 23D

Level Off

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Attitude Ind.	460	.42	.48	.20	194
Heading Ind.	321	.50	.33	.17	160
PALT	106	.35	.11	.04	37
VV	241	.43	.25	.11	104
IAS	87	.46	.09	.04	40
XPT	159	.29	.17	.05	47
Other	23	.30	.02	.01	7
Nu	880	.42	.92	.39	371

Ss = 16, Tr = 60, TR = 960

TABLE 24D

Climb

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Attitude Ind.	589	.39	.61	.24	230
Heading Ind.	366	.54	.38	.20	196
PALT	77	.43	.08	.03	33
VV	125	.43	.13	.06	53
IAS	220	.48	.23	.11	106
XPT	102	.32	.11	.03	32
Other	3	.23	--	--	1
Nu	700	.44	.73	.32	308

Ss = 16, Tr = 60, TR = 960

TABLE 25D

Left Turn

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Attitude Ind.	851	.44	.89	.39	371
Heading Ind.	208	.63	.22	.14	132
PALT	110	.42	.11	.05	46
VV	304	.51	.32	.16	154
IAS	25	.35	.03	.01	9
XPT	88	.26	.09	.02	24
Other	1	--	--	--	0
Nu	483	.46	.50	.23	223.82

Ss = 16, Tr = 60, TR = 960

TABLE 26D

Right Turn

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Attitude Ind.	830	.46	.86	.40	386
Heading Ind.	210	.45	.22	.10	95
PALT	123	.35	.13	.04	43
VV	271	.36	.28	.10	97
IAS	39	.23	.04	.01	9
XPT	133	.31	.14	.04	41
Other	2	.22	--	--	--
Nu	678	.42	.71	.30	285

Ss = 16, Tr = 60, TR = 960

TABLE 27D

Cruise

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Attitude Ind.	593	.43	.62	.26	253
Heading Ind.	312	.56	.32	.18	175
PALT	119	.39	.12	.05	46
VV	308	.54	.32	.17	167
IAS	45	.29	.05	.01	13
XPT	137	.27	.14	.04	37
Other	1	.22	--	--	--
Nu	584	.46	.61	.28	267

Ss = 16, Tr = 60, TR = 960

TABLE 28D

Fast Rate Let Down

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Attitude Ind.	523	.42	.54	.23	218
Heading Ind.	319	.50	.33	.17	161
PALT	219	.60	.23	.14	132
VV	149	.42	.15	.06	63
IAS	116	.48	.12	.06	56
XPT	94	.32	.10	.03	30
Other	7	.45	.01	--	3
Nu	639	.46	.67	.31	297

Ss = 16, Tr = 60, TR = 960

Tables 29D and 30D are from data given in a "Comparative Study of Pilot Fatigue Resulting From Extended Instrument Flight Using the Standard AAF and British Instrument Panels" by W. McGehee. Table 29D was produced by experienced AAF pilots and Table 30D by less experienced U. S. Navy pilots.

TABLE 29D

Six-Minute Instrument Pattern

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon				.21	3542
Directional Gyro				.20	3525
PALT				.11	1814
VV				.03	449
IAS				.23	4026
TS				.06	1019

Ss = 8, Tr = 2160, TR = 17280

TABLE 30D

Six-Minute Instrument Pattern

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon				.28	3681
Directional Gyro				.19	2462
PALT				.05	700
VV				.05	622
IAS				.14	1776
TS				.04	570

Ss = 6, Tr = 2160, TR = 12960

Further work by W. McGehee produced the data for Tables 31D, 32D and 33D. Table 31D data was obtained from USN aviation cadets with 15 hours instrument training, Table 32D from newly graduated pilots and Table 33D from flight instructors. These data were reported in USAF TR-5837.

TABLE 31D
Four-Minute Instrument Flight

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	2098	.58	.58	.34	1217
Directional Gyro	1492	.54	.41	.22	806
PALT	783	.51	.22	.11	400
VV	117	.43	.03	.01	50
IAS	699	.51	.19	.10	356
TS	713	.51	.20	.10	364
Clock	547	.52	.15	.08	284

Ss = 15, Tr = 240, TR = 3600

TABLE 32D
Four-Minute Instrument Flight

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	2292	.56	.68	.38	1283
Directional Gyro	1651	.47	.49	.23	776
PALT	874	.45	.26	.12	393
VV	288	.35	.09	.03	101
IAS	481	.51	.14	.07	245
TS	525	.48	.16	.07	252
Clock	588	.56	.17	.10	329

Ss = 14, Tr = 240, TR = 3360

TABLE 33D
Four-Minute Instrument Flight

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	1267	.50	.53	.26	634
Directional Gyro	1179	.45	.49	.22	530
PALT	725	.47	.30	.14	341
VV	120	.60	.05	.03	72
IAS	453	.53	.19	.10	240
TS	437	.50	.18	.09	218
Clock	811	.37	.34	.12	300

Ss = 10, Tr = 240, TR = 2400

Tables 34D and 35D are from "The Measurement and Analysis of Pilot Scanning and Control Behavior During Simulated Instrument Approaches" by D. H. Weir and R. H. Klein.

TABLE 34D

Approach ILS

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Attitude Ind.	881	.85	.52	.44	749
HSI/GSD	833	.96	.49	.47	800
PALT	79	.43	.05	.02	34
VV	158	.43	.09	.04	68
IAS	49	.70	.03	.02	34

Ss = 3, Tr = 100, TR = 1702

TABLE 35D

Approach Flight Director

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Flight Director	439	1.93	.40	.77	852
Glide Slope	213	.52	.18	.10	111
PALT	111	.40	.10	.04	44
VV	50	.44	.04	.02	22
IAS	121	.55	.11	.06	66

Ss = 3, Tr = 100, TR = 1106

Tables 36D and 37D recreate a six-minute Navy "O" instrument pattern by using comparable portions of flight data from USAF TR-5975 and 6018 and from the UH-1B for comparison with the McGehee study. The Navy "O" or Oscar Pattern is shown in Figure 1D.

SYNTHESIZED SIX-MINUTE PATTERN (NAVY "O")

TABLE 36D

USAF TR-5975, TR-6018 Data

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Gyro Horizon	2233	.65	.40	.26	1445
Directional Gyro	2371	.61	.42	.26	1459
PALT	965	.45	.17	.08	437
VV	816	.47	.15	.07	384
IAS	1439	.58	.26	.15	840
TS	559	.45	.10	.04	250
Engine Group	407	1.07	.07	.08	434

TR = 5520

TABLE 37D

UH-1B Data

INSTRUMENT	Ni	\overline{Td}	\overline{fs}	n	Ti
Attitude Ind.	288	.61	.23	.14	175.01
PALT	320	.59	.25	.15	188.51
VV	114	.53	.09	.05	61.01
IAS	178	.47	.14	.07	84.44
RMI	88	.65	.07	.05	57.6
TS	13	.42	.01	--	5.49
Engine Group	227	.69	.18	.12	157.6
Clock	4	.50	--	--	2.0

TR = 1257

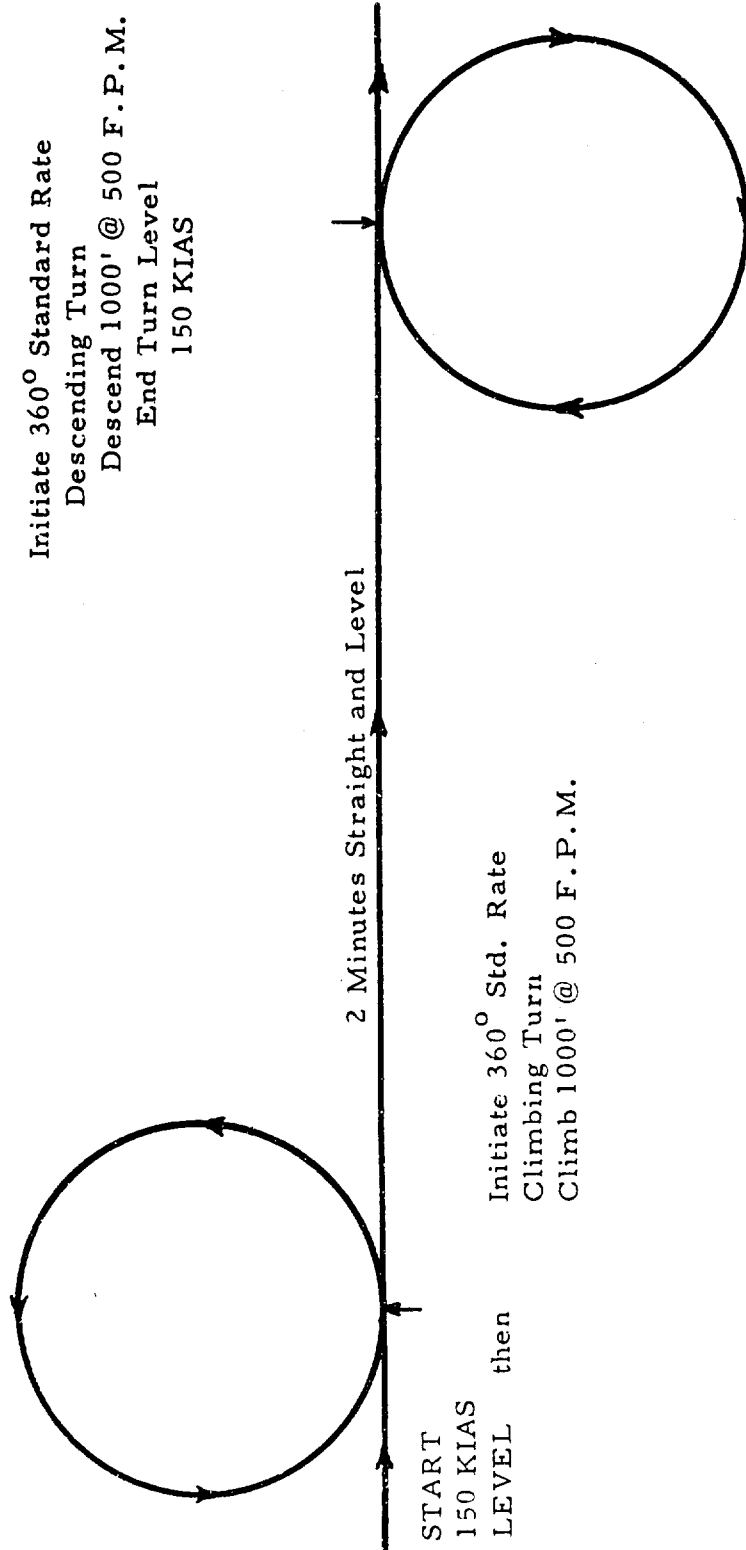


Fig. 1D. "Oscar Pattern," NATOPS Flight Manual 01-85SAB-501

Tables 38D, 39D and 40D are from data given in "Human Visual Sampling Processes: A Simulation Validation Study" by J. W. Senders, J. R. Carbonell, and J. L. Ward.

TABLE 38D

Approach ILS

INSTRUMENT	n	Ti
Attitude Ind.	.28	336
Heading	.21	252
PALT	.07	84
VV	.13	156
IAS	.07	84
XPT	.23	276

Ss = 2, Tr = 200, TR = 1200 (3 Trials/Ss)

TABLE 39D

360-Degree Turn

INSTRUMENT	n	Ti
Attitude Ind.	.41	738
Heading	.22	396
PALT	.19	342
VV	.08	144
IAS	.09	162

Ss = 3, Tr = 200 TR = 1800 (3 Trials/Ss)

TABLE 40D

Descent

INSTRUMENT	n	Ti
Attitude Ind.	.41	492
Heading	.22	264
PALT	.14	168
VV	.08	96
IAS	.15	180

Ss = 2, Tr = 200, TR = 1200 (3 Trials/Ss)

It is unfortunate that there was not sufficient data available from this study and the McGehee study, Tables 29D and 30D, to allow the compilation of complete tables.